Seema Arya

Petrophysics

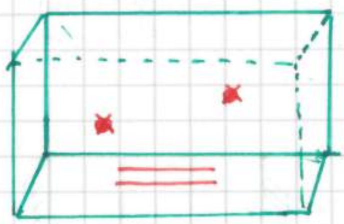
12.03.14 **Formation evaluation** (Brønnlogging)

Petrophysisist : physical and chemical properties of rocks and the interaction with the fluids in it water, HC (oil, gas).

- Porosity
- Lithology
- mineralogy

Investigation of subsurface

- Seismic data
- well logging



Data

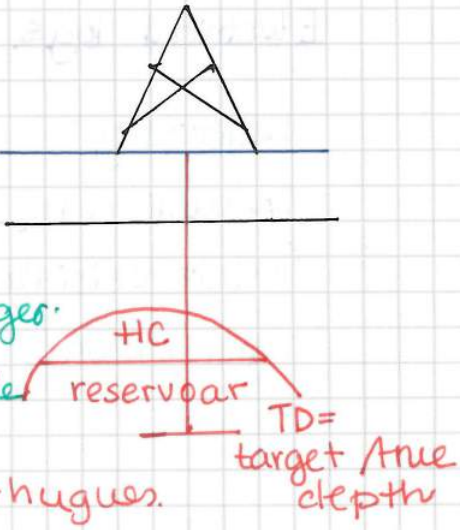
- well logs
- core data
- testing
- mud logging

1. Data collection / acquisition
2. Evalutation of data

Application → • geology • seismic • reservoar data

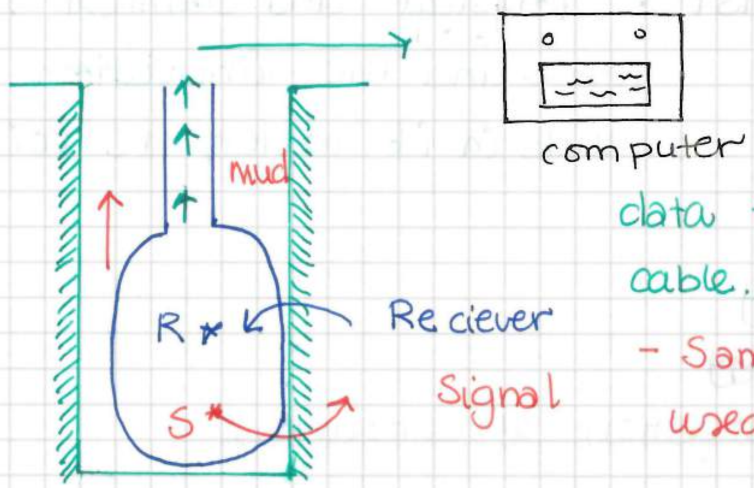
- evaluate
  - ↳ well
  - ↳ field
  - ↳ Reservoar

Open hole ↳ well logging
continuous record of geo. physical data along borehole



ex. Slumberger, halliburton, bakerhugues.

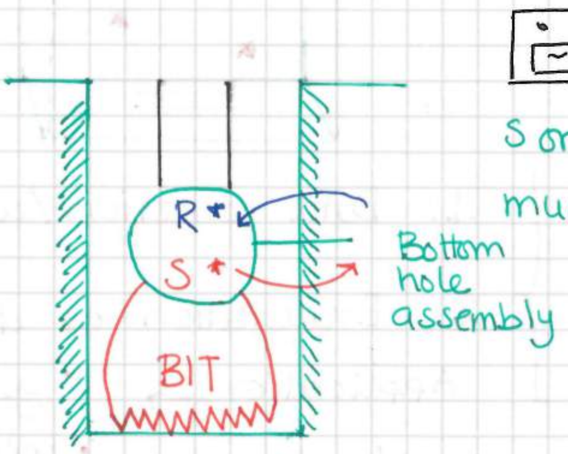
1. Wireline logging (WL)



data transmission through cable.

- Sampling every 15 cm useage 20-30%

2. Logging while drilling (LWG)



Some data transfered by the mud during drilling

- most data stored in BHA use 70-80%

LOGS

Electrical logs

Laterolog } HC
Induction log
microresisitivity log
Spontaneous potential SP } geology

Acoustic log

Sonic log } seismic

Radioactive logs

Gamma ray
Density log } geology, Φ (porosity)
Neutron

APPLICATIONS

#1. Geology

(a) Rocks / lithology (sandstone, shale...)

(b) Mineralogy

(c) Sedimentology

(d) Source rock

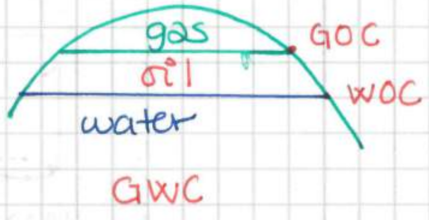
(e) well corelation

#2. Porosity

#3. Hydro carbon zone

fluid contacts GOC, WOC, GWC

water saturation (S_w)



#4. HC volume

A = area of reservoir

h = depth of reservoir

ϕ = porosity

S_w = water saturation

$$A \times h \times \phi (1 - S_w)$$

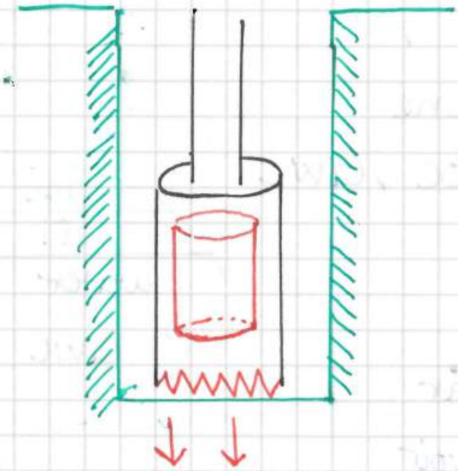
#5. Special applications

- seismic
- formation pressure
- Formation strength
- Fracture estimation
- Permeablity (K)

← Before Drilling After →

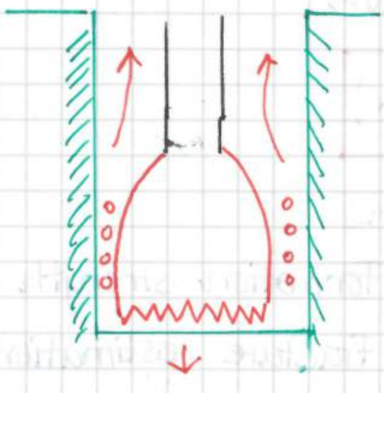
	Seismic	Seabed logging	well logging	Core	mud logging	testing
Geologist	×		×	×	×	
Geophysist	×	×	×			
Petrophysist			×	×	×	×
Reservior Ing			×	×		×
Production ing						×

3. Coring



→ samples of rocks
→ fluid testing

4. mud logging Cutting



→ with connect depth
→ analyse the rocks

5. Cable testing

→ Pressure , Temperature , depth

6. Measurement while drilling mud

→ directional data
→ geo steering (placement of horizontal well

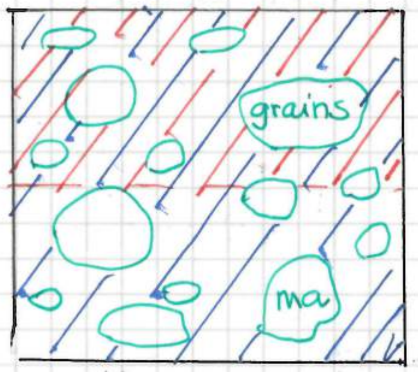
7. testing production phase

13.03 Petrophysics → determination of fluids in rocks
- water
- oil
- gas } volume HC.

⇒ compute water saturation S_w

$S_{hc} = 1 - S_w$
$S_w + S_{hc} = 1$

usually $S_{HC} = 0{,}75 - 0{,}85$
$S_w = 0{,}15 - 0{,}25$



Resisivity

Slumberger 1927

Intrinsic property of rock to resist the electrical current independant of shape / size

Ohm law → Resistance r

$$r = \frac{V}{I} \; (\Omega)$$

$$R = r \times \frac{A}{L} \; [\Omega m]$$

relative resistivity

$$V = r \cdot I$$

V: volts   I : Ampere (A)
r : ohm

Conductivity C

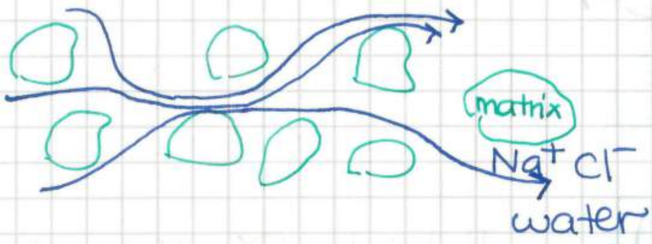
$C = \frac{1}{R}$ mS/m — ability to let the current pass.

salt water

$Na^+ \rightarrow Cl^-$

R_w = water resistivity

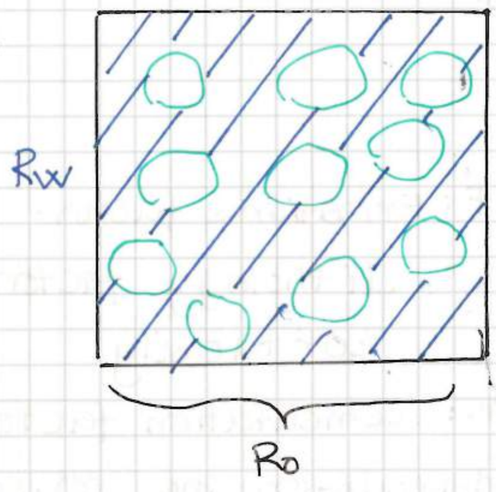
R very low ⇔ C very high



R fresh water >> R salt water

Hydrocarbon no $Na^+ Cl^-$

$$R_{HC} \gg R_{\text{salt water}}$$



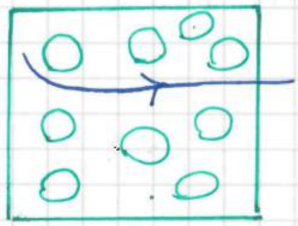
$$R_o = F \times R_w$$

F: formation resistivity factor

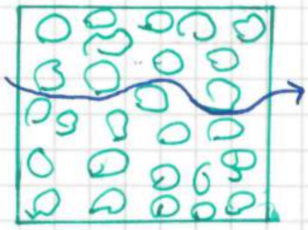
ARCHE

F
- constant for a formation
- undependant of Rw
- always > 1.

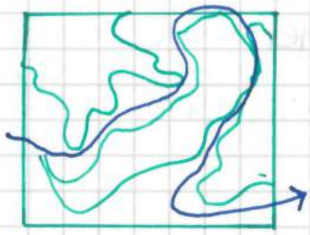
F • dependant of geometry
• dependant of porosity.



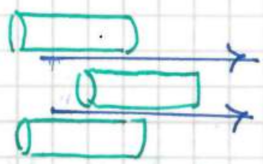
F low ≈ 10



F medium ≃ 50



F high ≃ 100-300



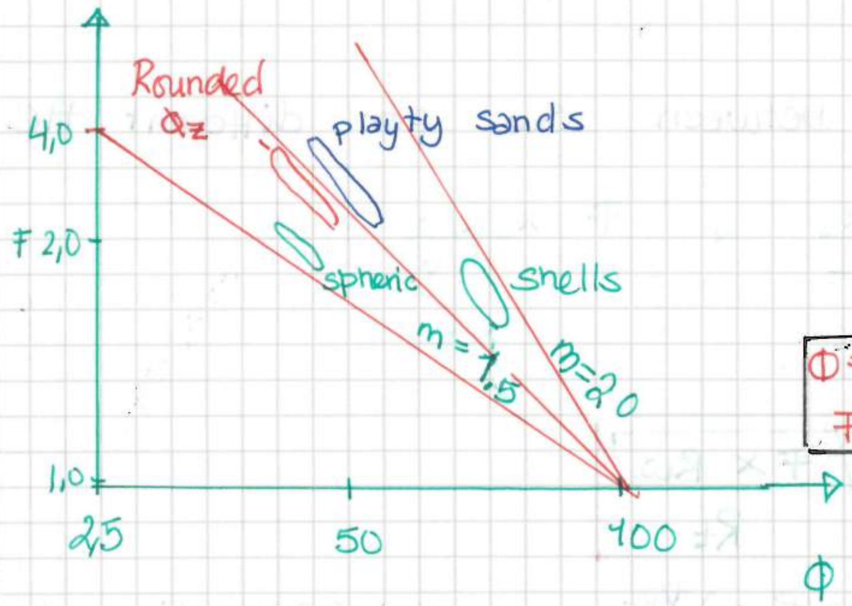
$F = \frac{1}{\Phi}$

ARCHIE 1942

- labratory tests

$$F = \frac{a}{\phi^m}$$

F : Formations factor
a : lithology factor
tortuosity
m : Cementation factor
depends on the consolidation
- grain size
- distribution



$\log F = -m\log$
$+ \log a$

$\Phi = 100\%$
$F = a$

Ideal sandstones

$a = 1$

$m = 2,0$

$$F = \frac{1}{\Phi^2}$$

tight limestones, chalks

- most of consolidated Ss

$$F = \frac{0,81}{\Phi^2}$$

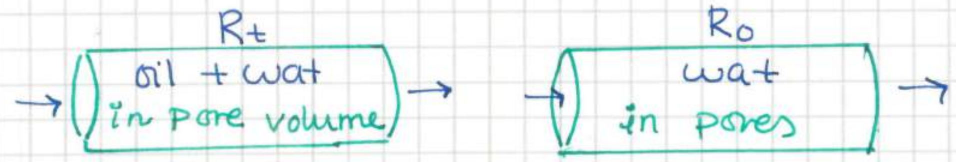
Timur ($\simeq$ 2000 samples)

$$F = \frac{1,13}{\Phi^{1,73}}$$

HUMBLE → typical Ss

$$F = \frac{0,62}{\Phi^{2,15}}$$

Archie equation



* $R_t > R_o$

Relation between Sw for different HC.

$$S_w^2 = \frac{R_o}{R_t} = F \times \frac{R_w}{R_t}$$

$$F = \frac{R_o}{R_w}$$

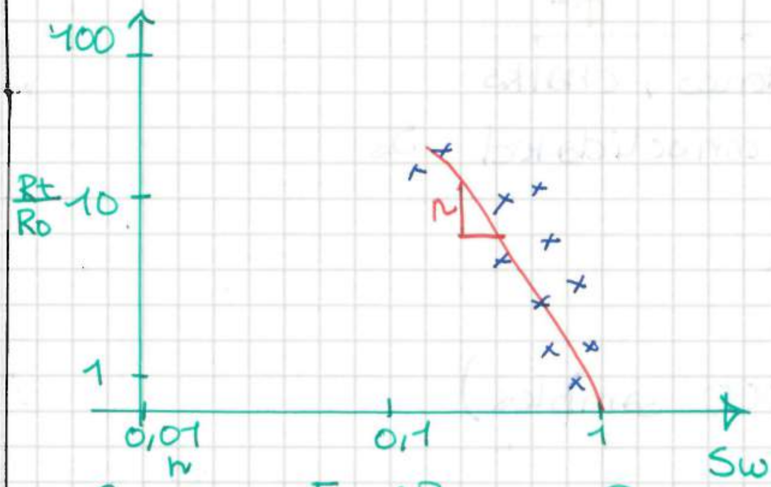
$$S_w = \sqrt{\frac{F \times R_w}{R_t}}$$

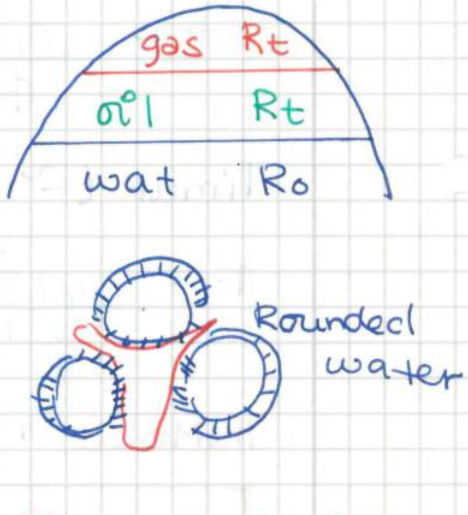
$$S_w = \left(\frac{F \times R_w}{R_t}\right)^{1/n}$$

n : saturation factor

$1,8 < n < 25$

$n = 20$





$$S_w^n = \frac{F \times R_w}{R_t} = \frac{R_o}{R_t}$$

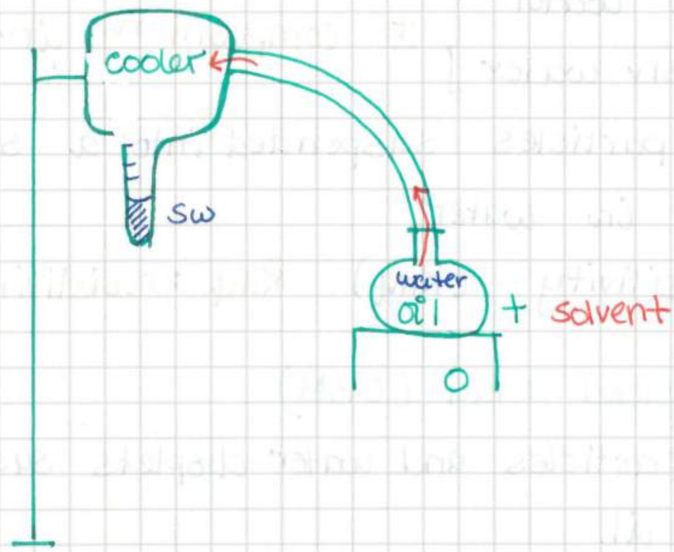
$$S_w^{-n} = \frac{R_t}{R_o}$$

$$-n \log S_w = \log (R_t/R_o)$$

$S_{HC} = 1 - S_w > 0$

Cores

Dean and stark distillation :

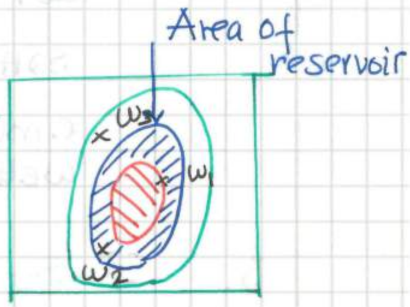


why do we want Sw

1. HC volume

$= A \times h \times \phi (1 - S_w) \quad N\uparrow$

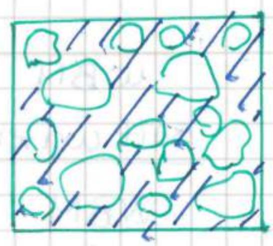
$= A \times h \times \phi \times \frac{N}{G} (1 - S_w)$



2. Reservoir Simulation

$\frac{N}{G}$ net to gross

available pore volume



18.03

Drilling fluids

1. water based mud (WBM)
   - salt water
   - fresh water

   } ± composition in salt

   solid particles suspended into a solution of salts in water

   Resisitivity (Rmf) Rmf : resistivity mud flitrate

2. Oil based mud (OBM)

   Solid particles and water droplets suspended in refined oil.

   50% oil

   20% water

   salts

   emulsifies

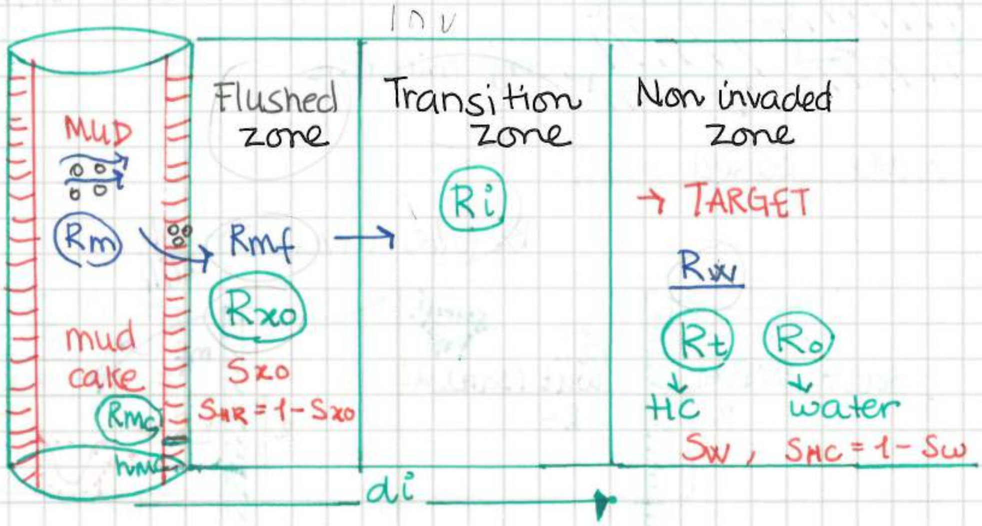
   wetting / weighting agents

   Rmf high

3. Synthetic based mud

	Fresh water formation	Salt water formation
WBM salt water	Rmf < Rw	Rmf ≷ Rw
WBM fresh water	Rmf ≷ Rw	Rmf > Rw
OBM	Rmf > Rw	Rmf > Rw

Invasion zones



Flushed zone

all mud filtrate replaced almost all water formation. R_{xo} = resistivity grains + mud filtrate. S_{xo} = water saturation of flushed zone

S_{HR} = saturation of residual HC

Transition

Less and less mud filtrate R_i

Non invaded zone

no mud filtrate

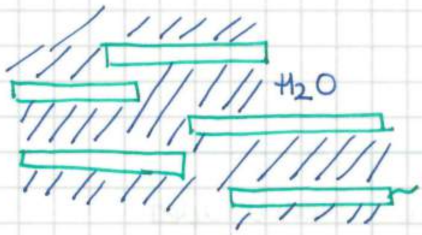
R_t : true resistivity with HC

R_o = —— " —— with water

S_w = water saturation

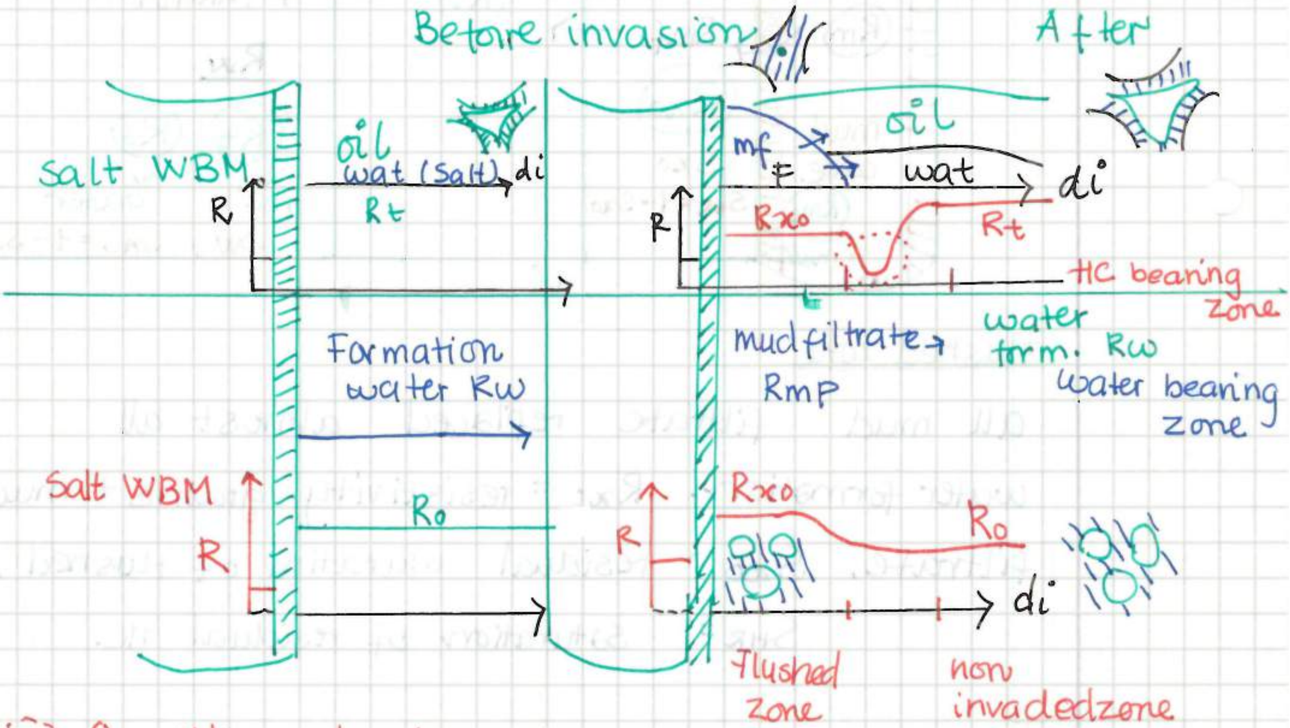
hmc = height of mud cake

shale resistivity



always low resisitivity
no movement of water.

water based mud



Oannulus due to water

R_o : $F \times R_w$ F : formation factor

$$F = \frac{a}{\Phi^m} \qquad S_s \cdot F = \frac{0{,}62}{\Phi^{2{,}15}}$$

HC zone (non invaded)

$$S_w = \sqrt{\frac{F \times R_w}{R_t}} \iff F = S_w^2 \frac{R_t}{R_w}$$

hypothesis = $S_{xo} = S_w^{1/5}$

$$S_w^2 \frac{R_t}{R_w} = S_{xo}^2 \frac{R_{xo}}{R_{mf}} \quad (*)$$

Flushed zone

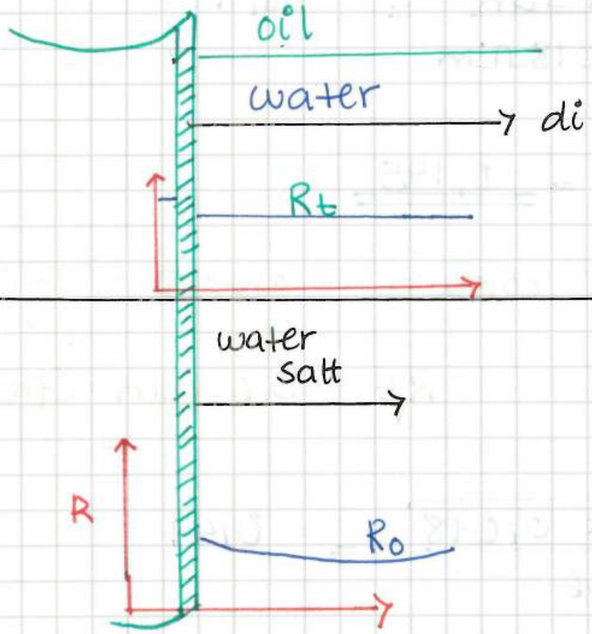
$$S_{xo} = \sqrt{\frac{F \times R_{mf}}{R_{xo}}} \iff F = S_{xo}^2 \frac{R_{xo}}{R_{mf}}$$

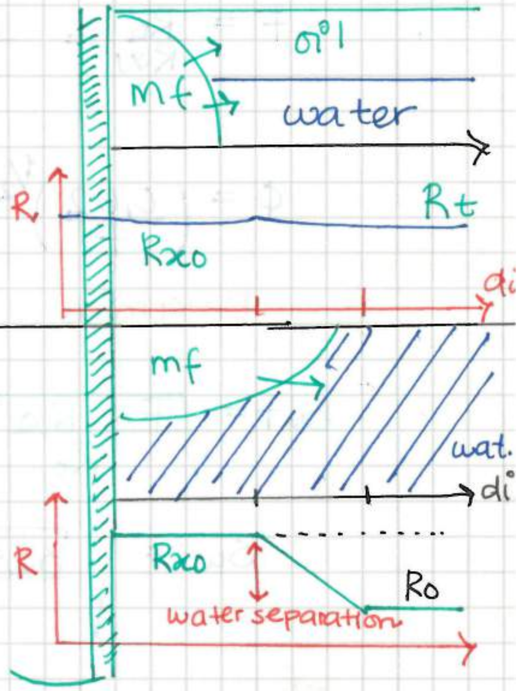
$$(*) = S_w = S_{xo}\sqrt{\frac{R_{xo}}{R_{mf}} \times \frac{R_w}{R_t}}$$

$$\Rightarrow S_w = S_w^{1/5} \left(\frac{R_{xo}}{R_{mf}} \times \frac{R_w}{R_t} \right)^{1/2}$$

$$\Rightarrow \boxed{S_w = \left(\frac{R_{xo} / R_t}{R_{mf} / R_w} \right)^{5/8}}$$

oil based mud (OBM)





Low resistivity → shale

high resisitivity → sandstone (Lines seperated)

$R_w = 0{,}018\ \Omega m$

$R_{mf} = 0{,}2\ \Omega m$ at $75\ °F$

$T_f = 155°F$

$10\ ft = 3{,}048\ m$

19/03 Exercise 1 :

1) Calculate ϕ in sand zone and water saturation (S_w) in oil zone.

$$F = \frac{0{,}62}{\phi^{2{,}15}} \quad \text{Humble}$$

$$F = \frac{R_o}{R_w} = \frac{0{,}7\ \Omega m}{0{,}018\ \Omega m} = 38{,}9$$

$$\phi = \left(\frac{0{,}62}{F}\right)^{1/2{,}15} = 0{,}145$$

2) Determine oil coloum $= \Delta h \times \phi \times (1 - S_w)$ m^3/m^2

$$S_w = \sqrt{\frac{F \times R_w}{R_t}}$$

$R_t = 3{,}6\ \Omega m$ (from graph)

$$S_w = \sqrt{\frac{38{,}9 \times 0{,}018}{3{,}6}} = 0{,}44$$

Volume of HC : $\Delta h \times \phi (1 - S_w)$ m^3/m^2

h = 5cm → 12m
S O' = 15,26m
6,5cm

$2 \times 0{,}145 \times (1 - 0{,}44)$
$= 1\ m^3/m^2$

3) Residuel oil saturation (S_{hr}) in the invaded zone.

1) Sw in oil :

$$S_w = \left(\frac{R_{xo(oil)} / R_t}{R_{mf} / R_w}\right)^{5/8}$$

Chart 2 :

$$Rmf = \frac{Rmf_{ini}\,(T_{in} + 6{,}77)}{(T_f + 6{,}77)}$$

$$= \frac{0{,}2\,(75 + 6{,}77)}{155 + 6{,}77} = Rmf = 0{,}1\,\Omega m$$

$$Sw = \left(\frac{4{,}8/3{,}6}{0{,}1/0{,}018}\right)^{5/8} = 0{,}42 = Sw$$

(pretty accurate)

2) Φ from Rxo in water zone

$$\Phi = \left(\frac{0{,}62}{F}\right)^{2{,}15}$$

$$F = \frac{Rxo,wat}{Rmf} = \frac{2{,}9}{0{,}1} = 29 = F$$

$$\Phi = \left(\frac{0{,}62}{29}\right)^{2{,}15} = 0{,}167 = \Phi$$

3) S_{HR} (residual hydro carbon) in oil zone

$S_{HR} = 1 - Sxo$

$S_{HR} = 1 - 0{,}78$

$S_{HR} = 0{,}22$

$$Sxo = \sqrt{\frac{F \times Rmf}{Rxo(oil)}}$$

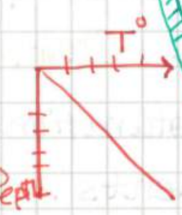
$$Sxo = \sqrt{\frac{29 \times 0{,}1}{4{,}8}} = 0{,}78$$

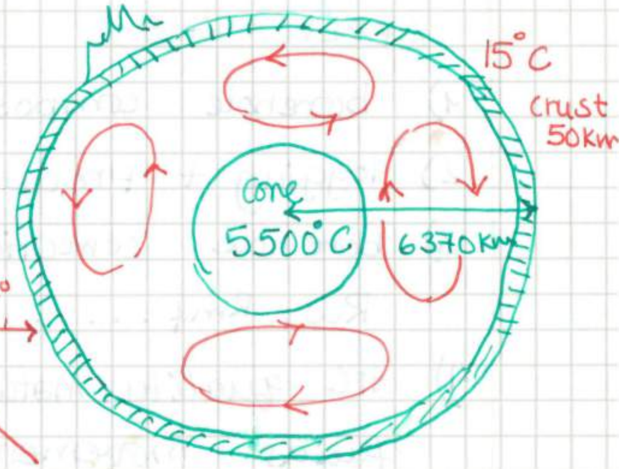
Temperature logging

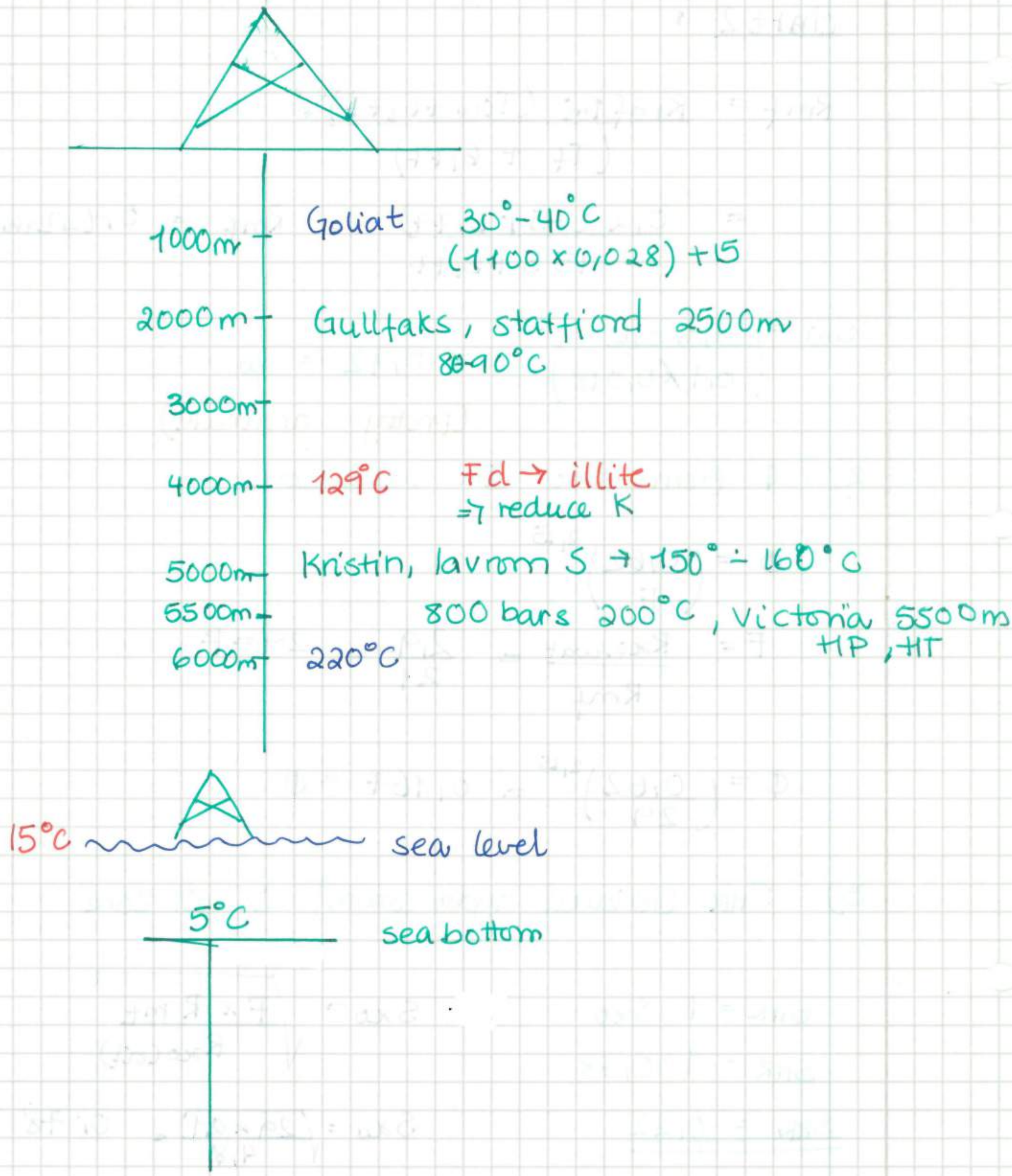
temperature gradient

$$\frac{T°formation - T°surface}{Depth}$$

2,8 °C / 100 m







APPLICATIONS

1) borehole composition / mud
2) logging + production material
3) bore hole correction petrophysical parameters
   R_w, R_{mf} ..... Chart ②
4) HC quality, maturation of source rock. viscosity, fluids movements. 5) Production

Measurments

until 1980's => thermometers

Now EMS = enviormental (schlumberg) measuring source. Continious measurement accuracy 0,1°C

TAP

Temperature

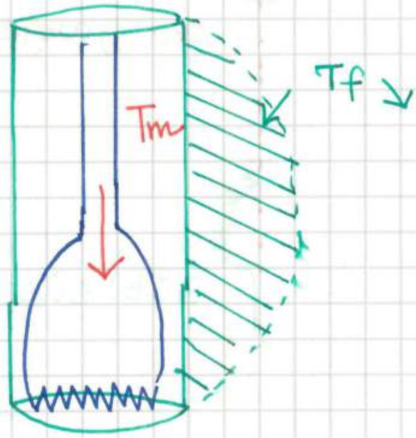
Acceleration

Pressure tool

high resolution. accuracy 0,005°C

Corrections

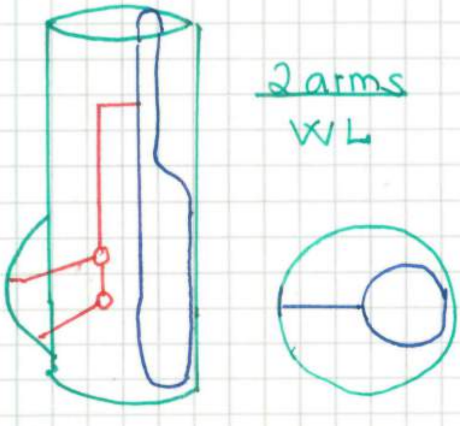
$T_m < T_f$

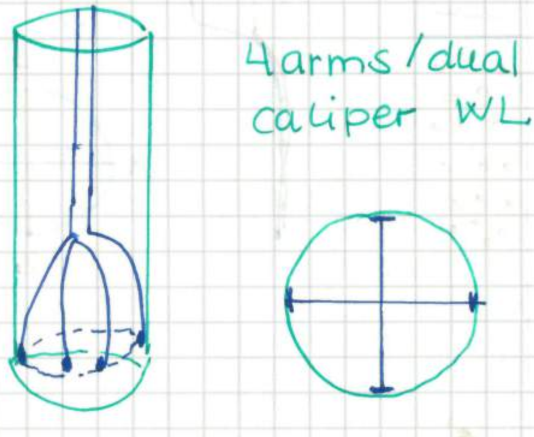


HORNER PLOT

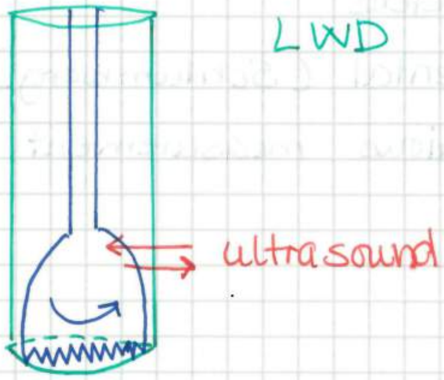
Caliper tool

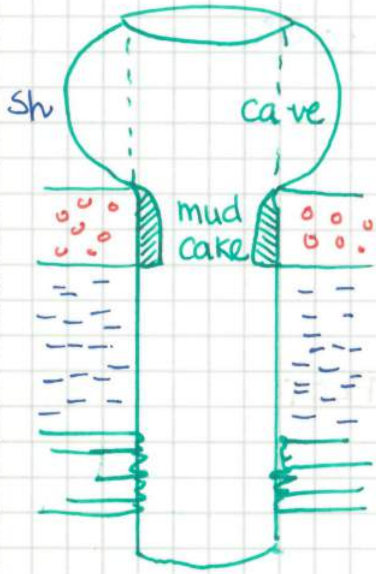
measures borehole size and shape

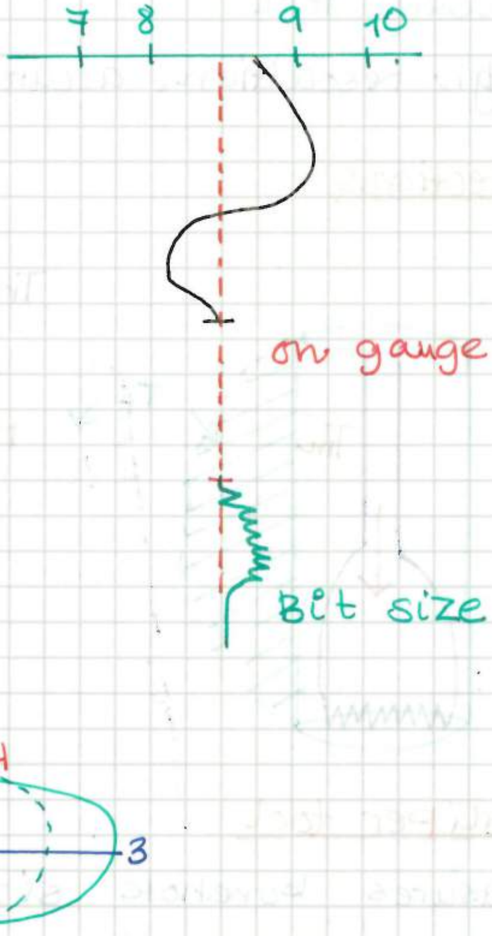


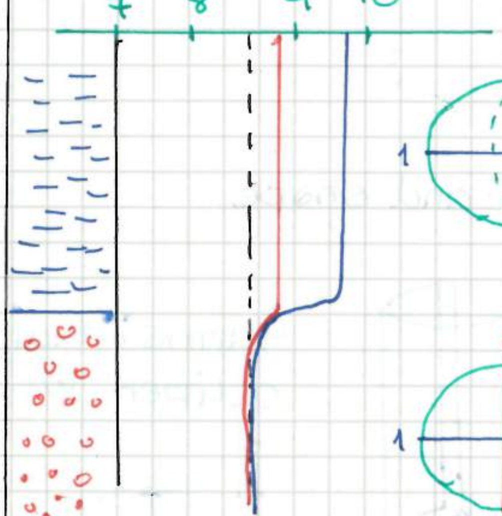


LWD 3D image


ultrasound


Sh
cave
mud cake


7
8
9
10
on gauge
Bit size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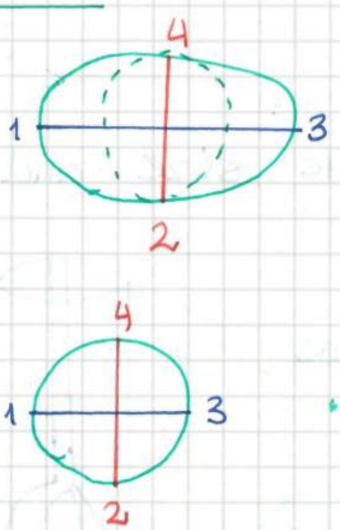
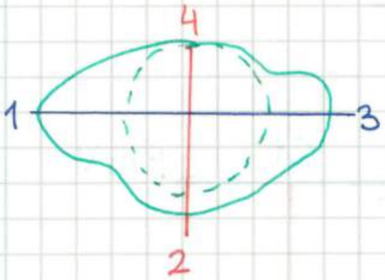
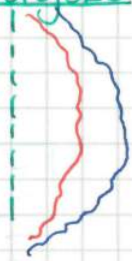
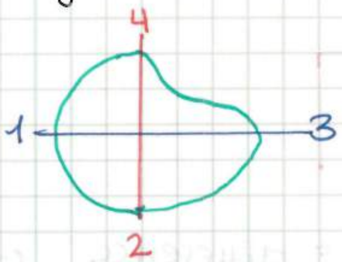

1
2
3
4

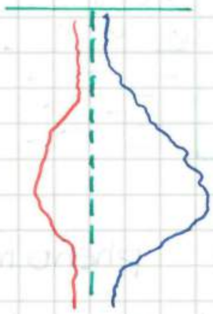
WASHOUT



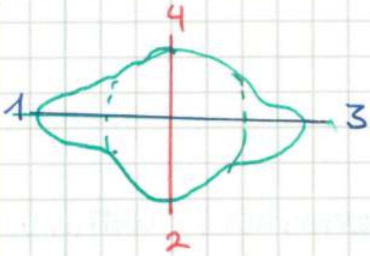


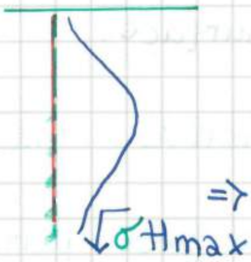
Key set

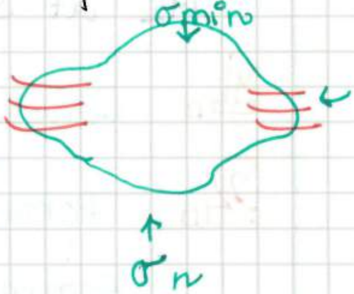


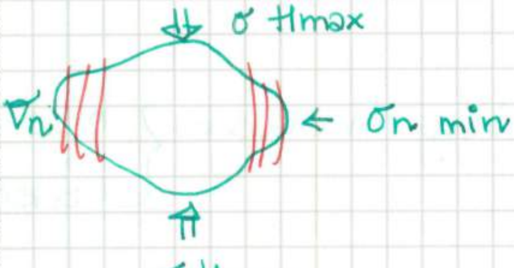


Breakouts

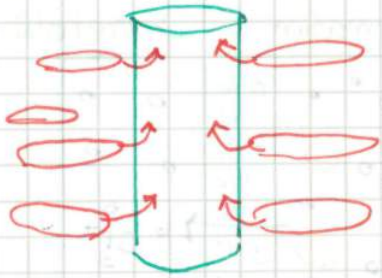




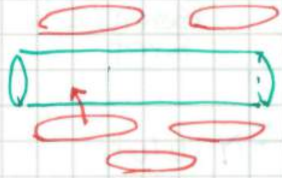




Spalling during drilling

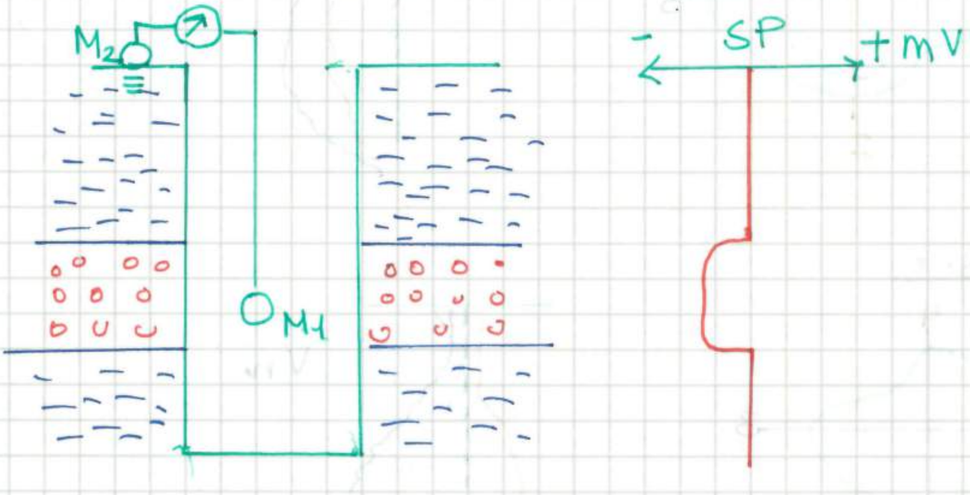


Good production



Not

20/03 Spontaneous Potential SP

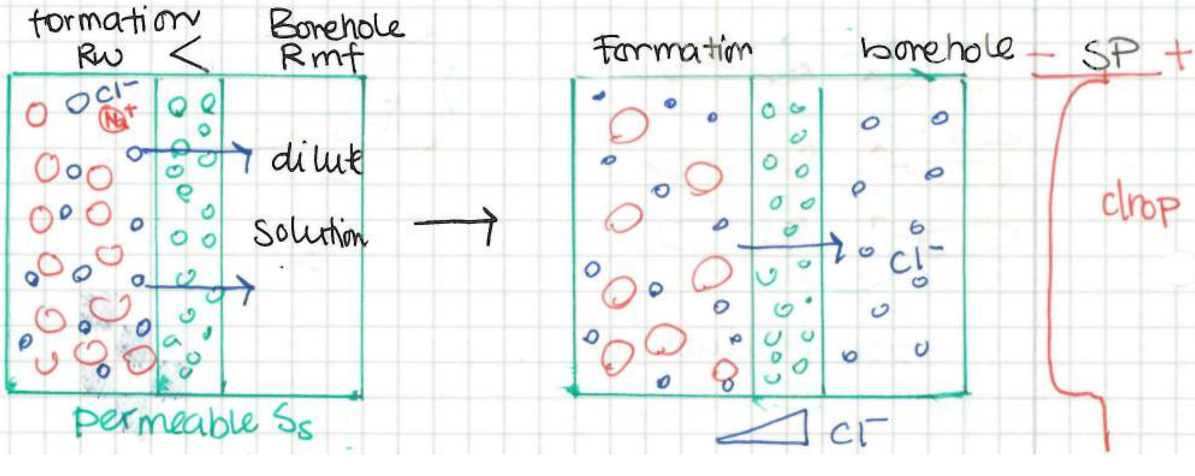


Record natural phenomenom = difference of electrical potensial between electrode M_1 in borehole and M_2 at surface.

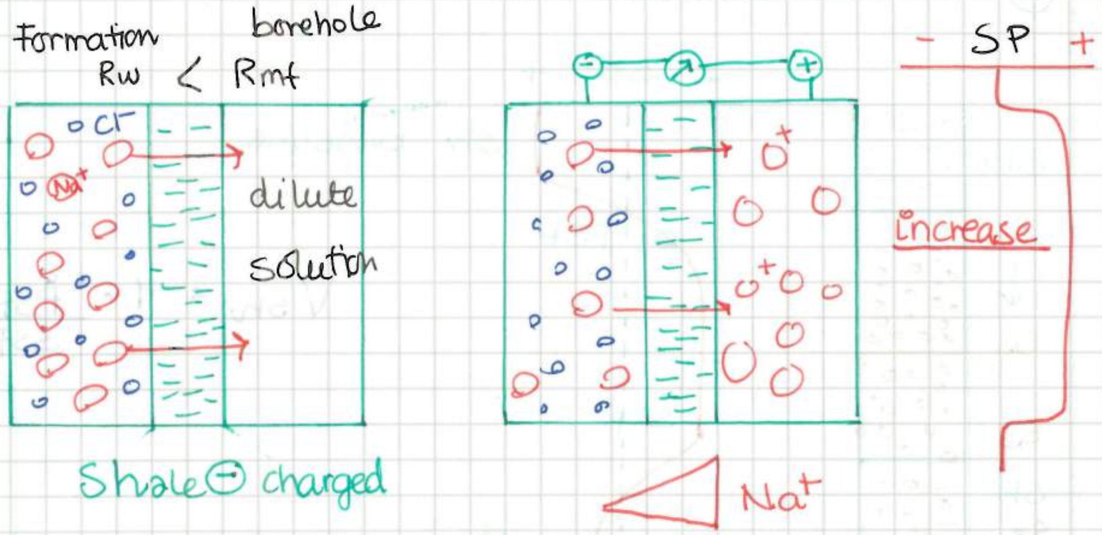
1. Conductive mud WBM
2. Porous and permeable formation within impermeab formations.
3. Difference of salinity between { mud filtrate Rm / water formation

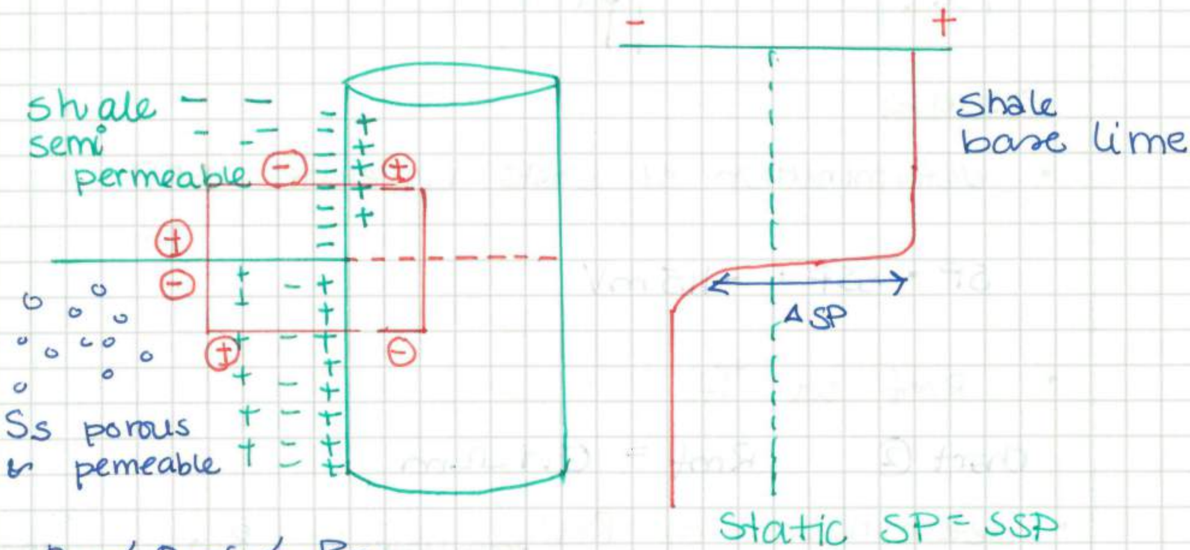
Principles

① Diffusion or liquid junction potensial



② shale or membrane potential





$R_w < R_{mf} < R_m$

Applications

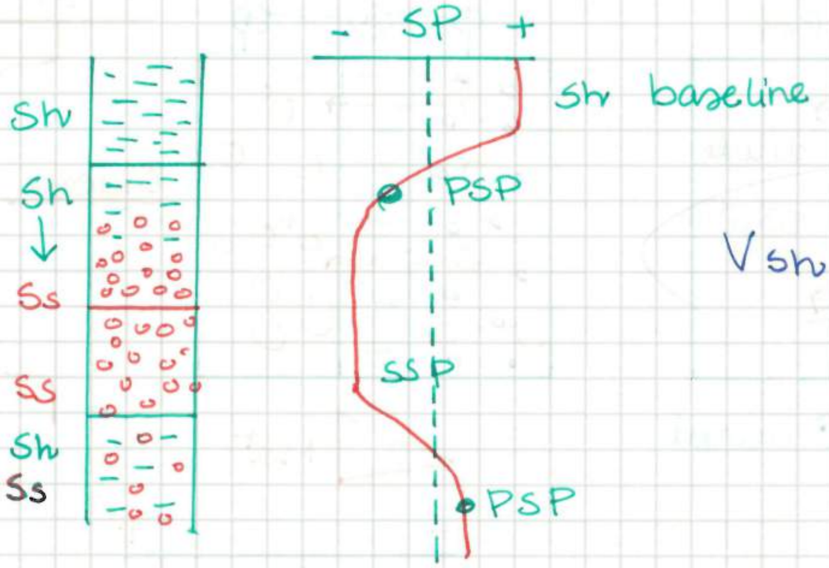
① R_w - theoretical value of SSP

$$SSP = -K^{\circ} \times \log \frac{R_{mf}}{R_w}$$

K - kelvin

$K = (0{,}133 \times T_{f\,°F}) + 66$

② Shale volume Vsh



$$V_{sh} = 1 - \frac{PSP}{SSP}$$

excercise

- determination of shale baseline SSP

SP = SSP = -115 mV

- Rmf at Tf

chart ② Rmf = 0,1 Ωm

- determination of $Rmf_{equivalent}$ - $Rw_{equivalent}$

chart ③

lit Rmf > 0,1 Ωm at 75°C - correction

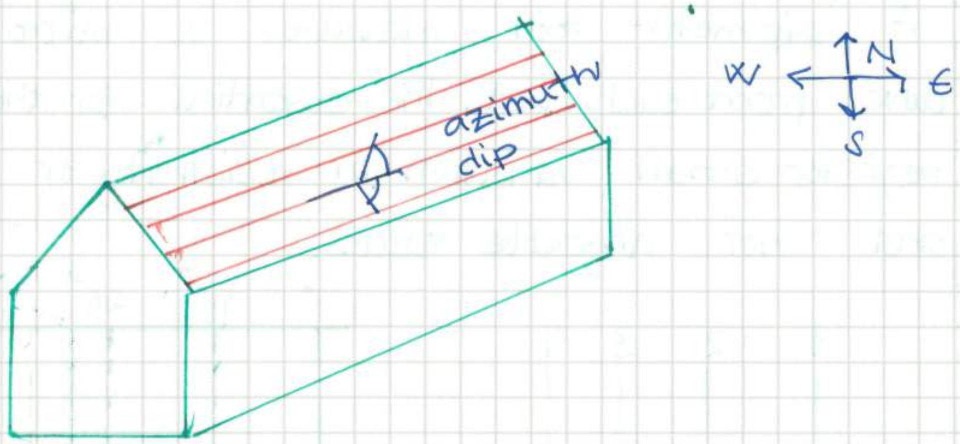
$Rmf_{eq} = 0,85 \times Rmf = 0,085$

Rmf_{eq} = 0,085 Ωm

Chart ③ = $\frac{Rmf_{eq}}{Rw_{eq}} = 21,5$

$$\frac{Rmf_{eq}}{Rw_{eq}} = \frac{Rmf}{Rw} \Rightarrow Rw_{eq} = \frac{Rmf_{eq}}{(Rmf/Rw)} = \frac{0,085}{21,5}$$

Rw_{eq} = 0,004 Ωm

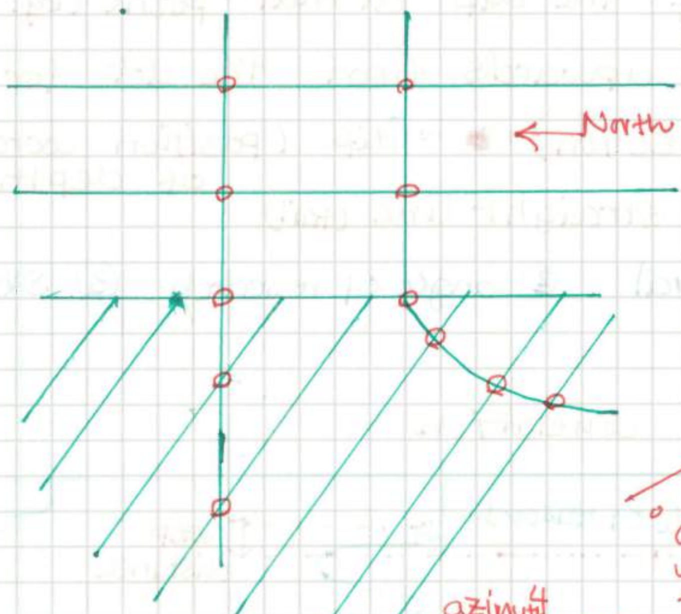


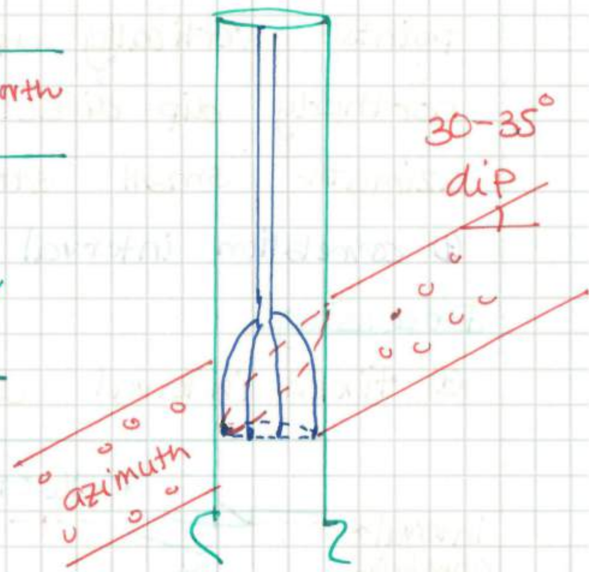
The dipmeter provides data for two different domain structural and sedimentary geology.

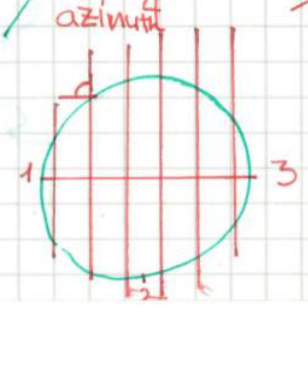
structural : unconformities, faults, folds, fractures

sedimentary : bedforms, reservior orientation, facies.

dipmeter tool : typically 4 pads, single electrode in each pad is usal, SHDT of slumberger has 2 on each pad. The pad pairs move in a plane normal to the tool axis.

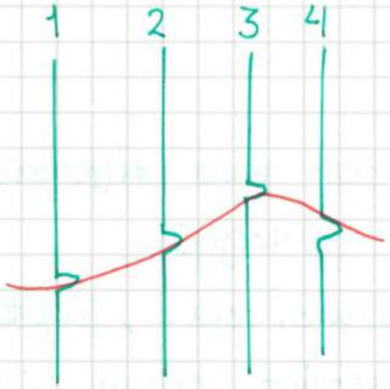


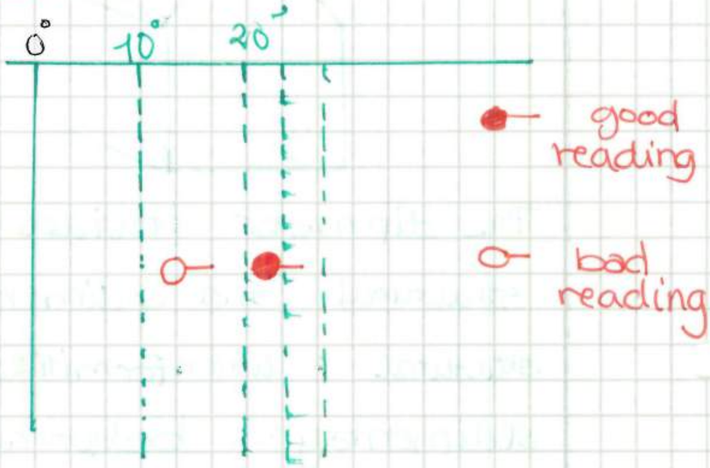




4 pads microresistivity measurement

A dipmeter tool measures a microresistivity curve from each pad. The essential for these curves is to register small variation in resistivity or conductivity. and not absoulte values.





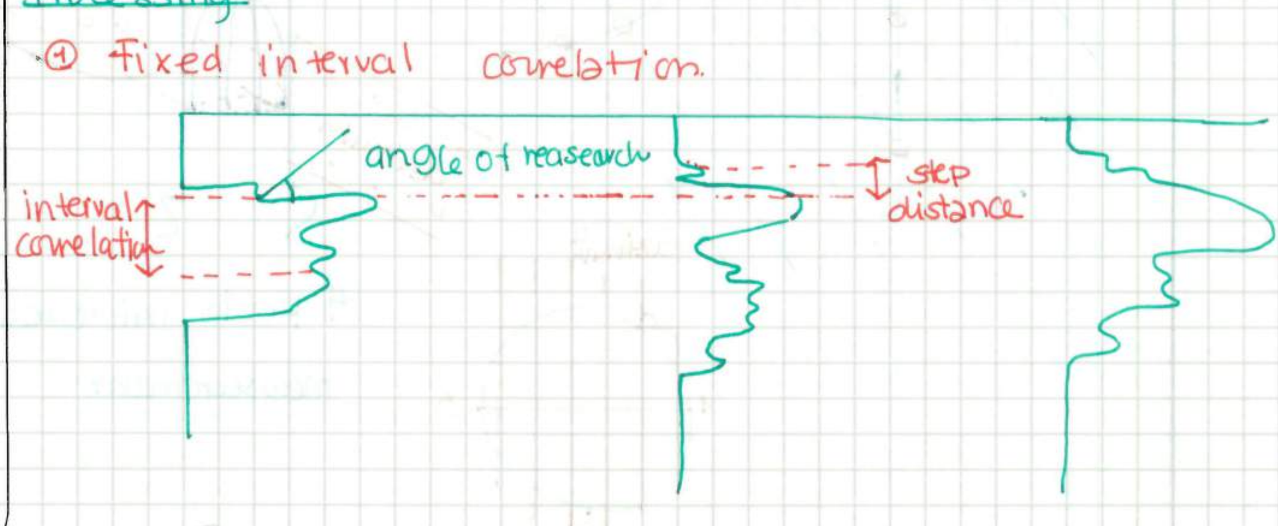
TADPOLE Plot

tadpole plot : a graf of dipmeter results. The bedding dip is plottet as a dot on depth-dip graf, and the dot is given a tail corresponding to the direction of the dip at that point (eg. the tail points vertically upwards from the dot for a northerly dip direction) ● = dip (position coordinate of depth) azimuth small straight line (tail).

① correlation interval ② angle of research ③ Step distance.

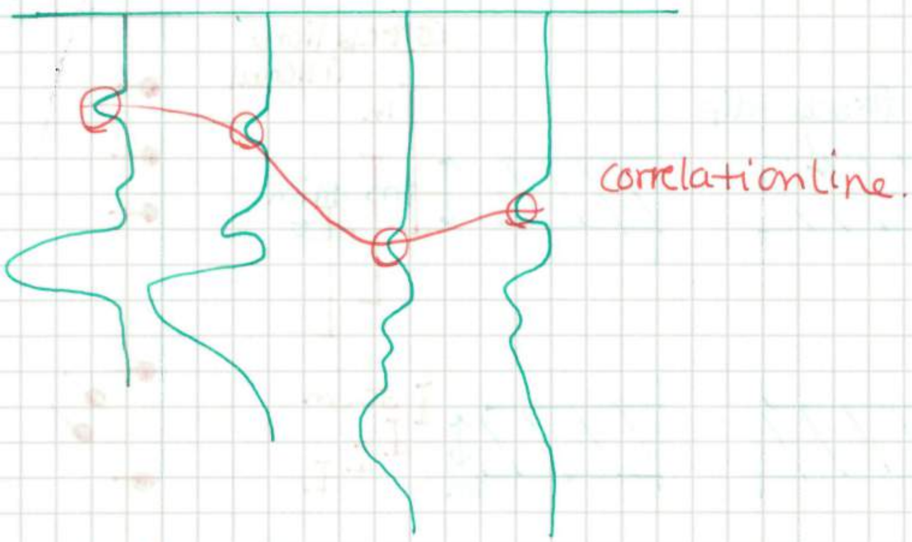
Processing

① Fixed interval correlation.



② feature recognition

try to correlate as will do the eyes.



Interpretation

dipmeter log presents a data set quite unlike any which a geologist working at outcrop will collect.

outcrop → geologist → choice (where to make measurement) → dip

dipmeter → tool → dips → Petrophysist to choose.

⇒ select and process in function of the structure / featheures you are looking. at.

Sedimentary dips

Includes laminations, crossbeds, forsets.

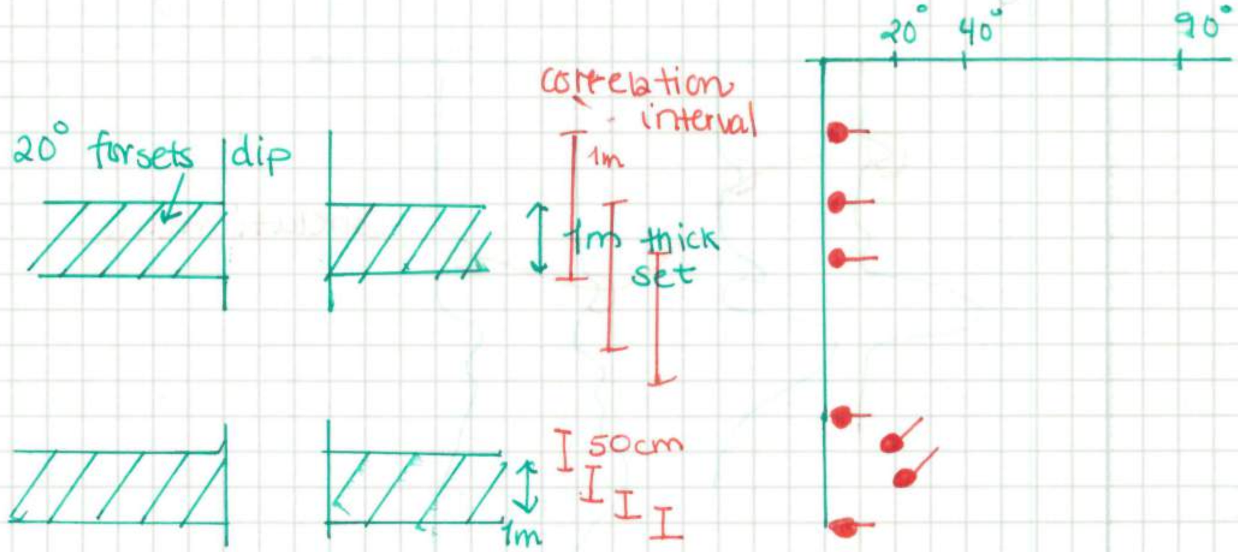
objective : to find orientation of reservoirs & reservoir parameters.

small corelation interval 15 cm

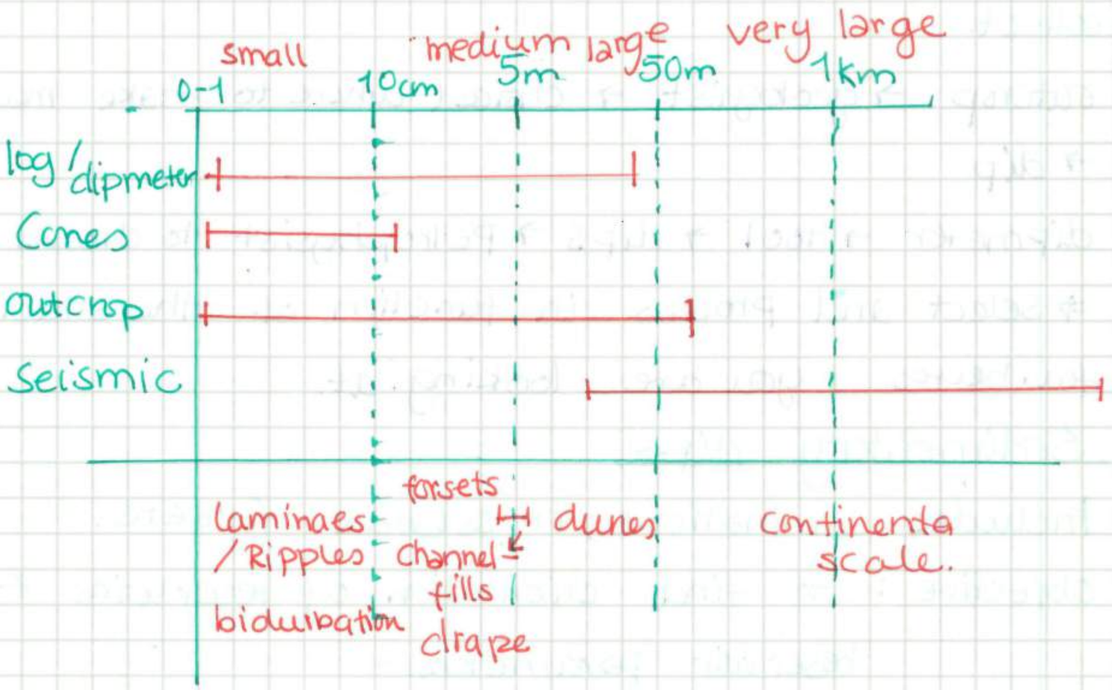
step distance 7-10 cm

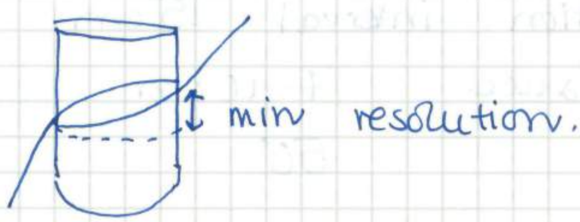
angle 50°

Fixed interval dipmeter processing parameters in relation to size (thickness) of sediment structure.



Dip meter resolution of sedimentary structures. Very small scale feature can be detected (not identified) by the dip meter curves.



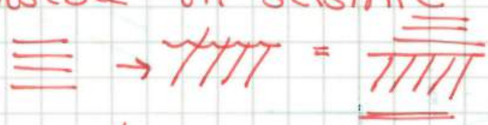


Structural dips

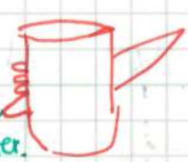
The general attitude of beds. Dip that would be measured at outcrop. A dipmeter log is processed for structural dip with relatively broad correlation interval 1m. step distance 50% so 50cm.

The search angle may be set reasonably low if the general dip is known.

angle of research 50°.

- bed dips → visible on seismic
- unconformities 
- faults 
- fractures

few outcrop analogues & models of orientation data useful for dipmeter.



fracture identification dipmeter microresistivity curve. Borehole imaging best tool.

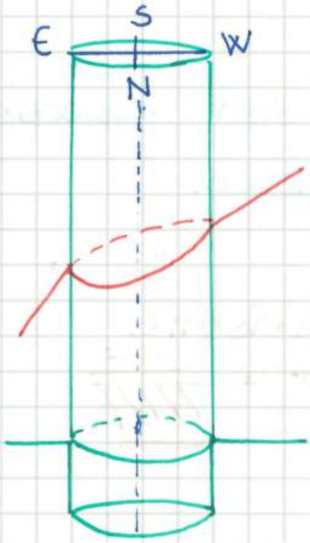
Image logs

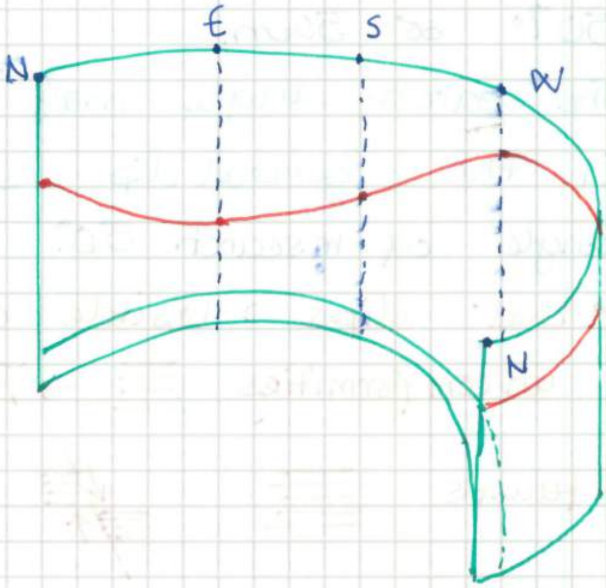
Formation is no sampled by a single sensor to create a single log, it is sampled many times horizontally and at high rate vertically, to form a dense matrix of measurements form which is created an image.

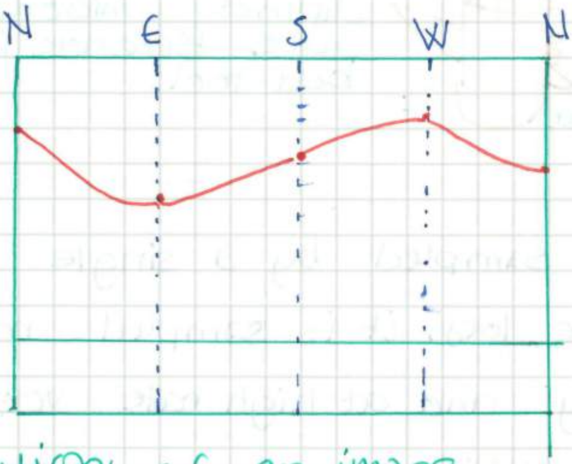
LWD → all logs can be converted to images
→ lower quality

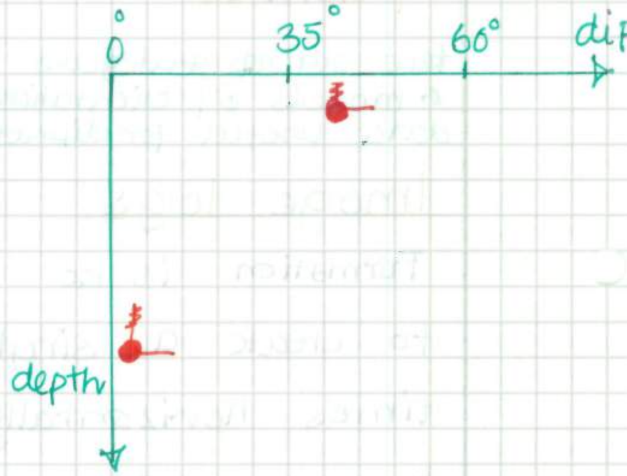
WL → electrical imaging, acoustic imaging
→ high quality

Representation of borehole wall images on a flat surface. Unrapping into a vertical depth grid and horizontal grid of compass bearings. Dipping is represented by a sinusoid.

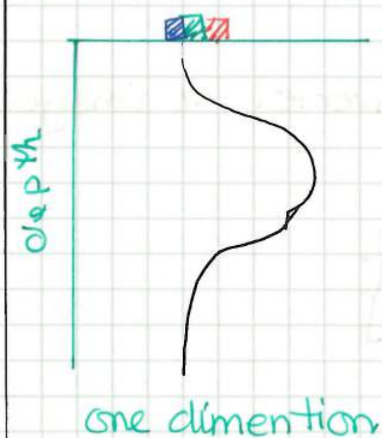


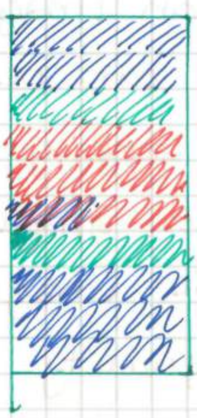






creation of an image

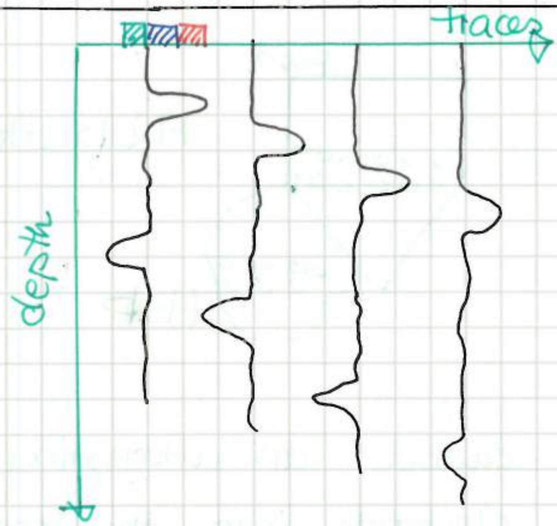


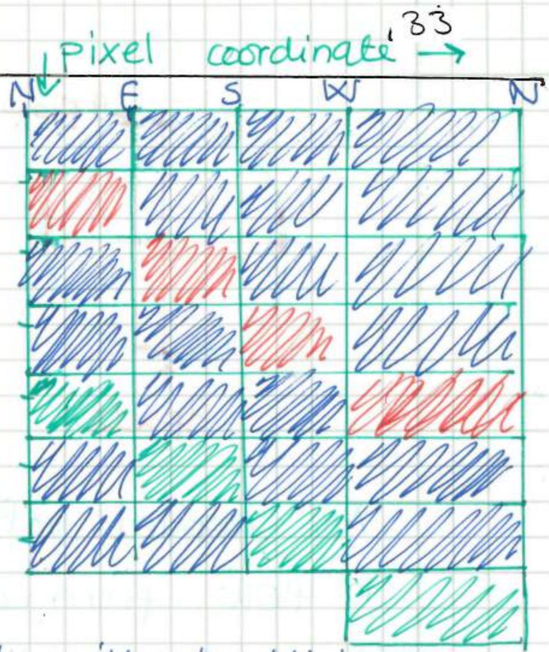


Producing an image from log responses.

1 dimensional method in which a defined range of log values is represented by a particular colour.

A banded colum is produced.





Two dimentional method used with multiple log traces. Each trace is sampled at regular verticle increments so that, with multiple log, a pixel matrix is achieved.

colour convention

Black	brown	orange	yellow	white

⊖ shale
⊖ coal
⊖ Ss/coal
⊕ ss/coal
⊕
⊖

R
ρ
GR
Neutron Φ
Sonic Δt
Amplitude

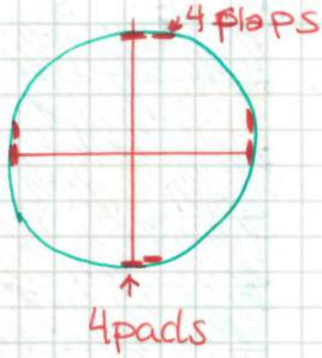
HC ⊕
coal
compact
sh organic ⊕
Ss ⊖
⊖
⊕

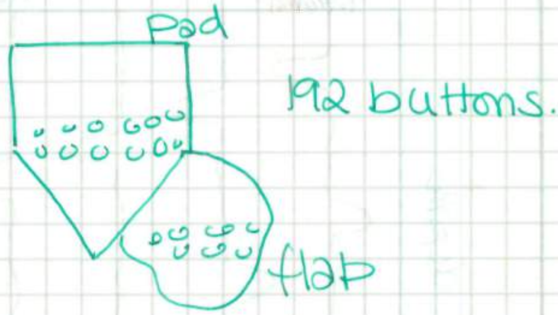
electrical imaging WL

FMI = Fullbore formation micro Imager

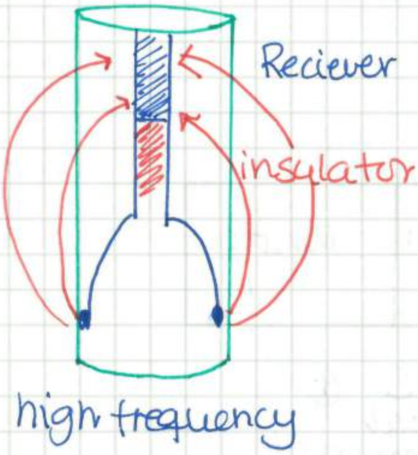
FMI provides 80% coverage in 8.5" borehole, with high quality.

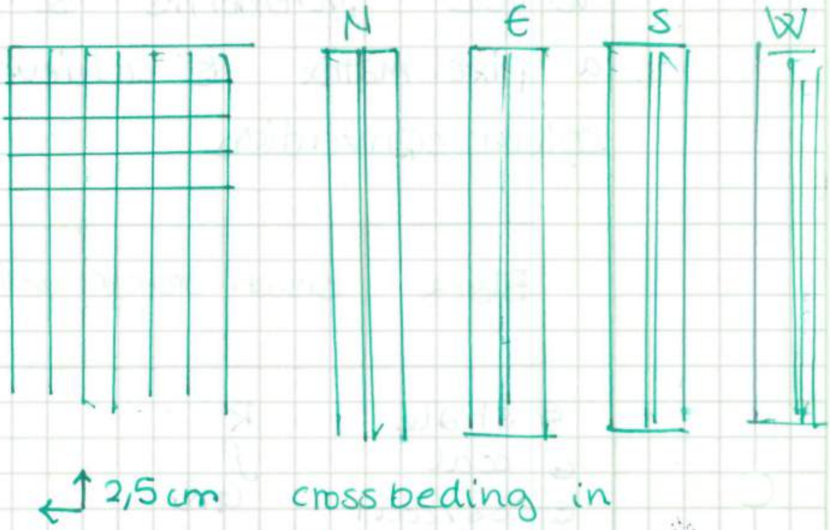
FMI consits of 4 pads on 2 orthogonal arms. 4 pad each have hinged flap so as to extend the area of electrical contact. Both pad & flap have arrays of 24 button electrodes.





An applied voltage causes an alternating current to flow from each electrode into the formation and then to be recieved at a return electrode on the upper part of the tool.

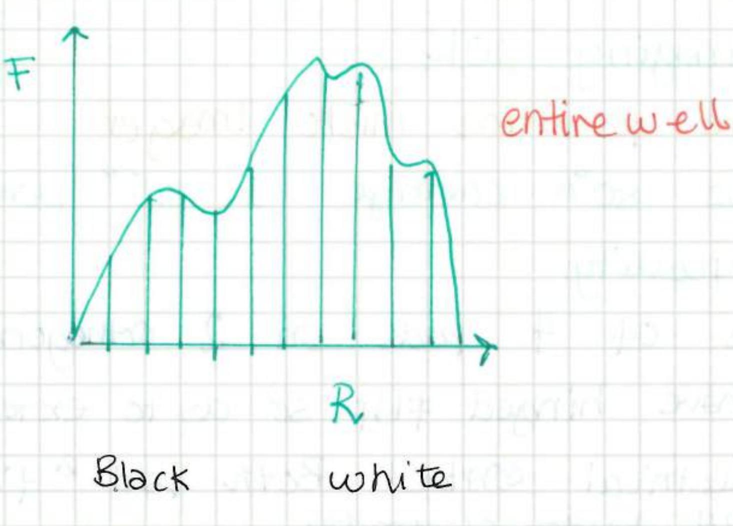




cross beding in electrical images.

Processing

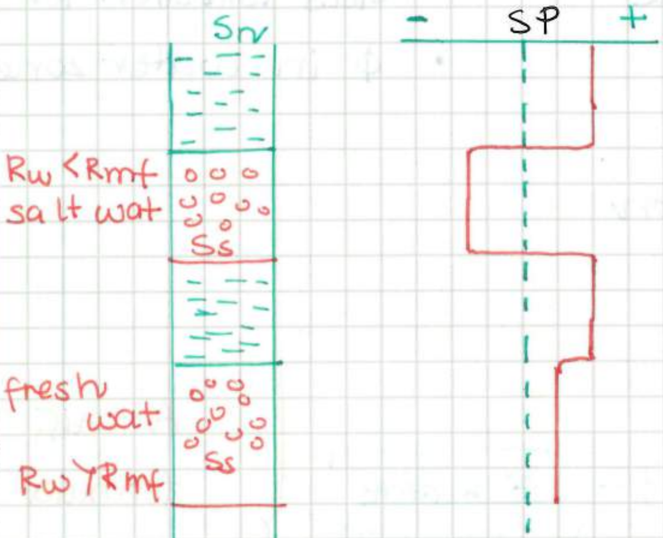
① Static



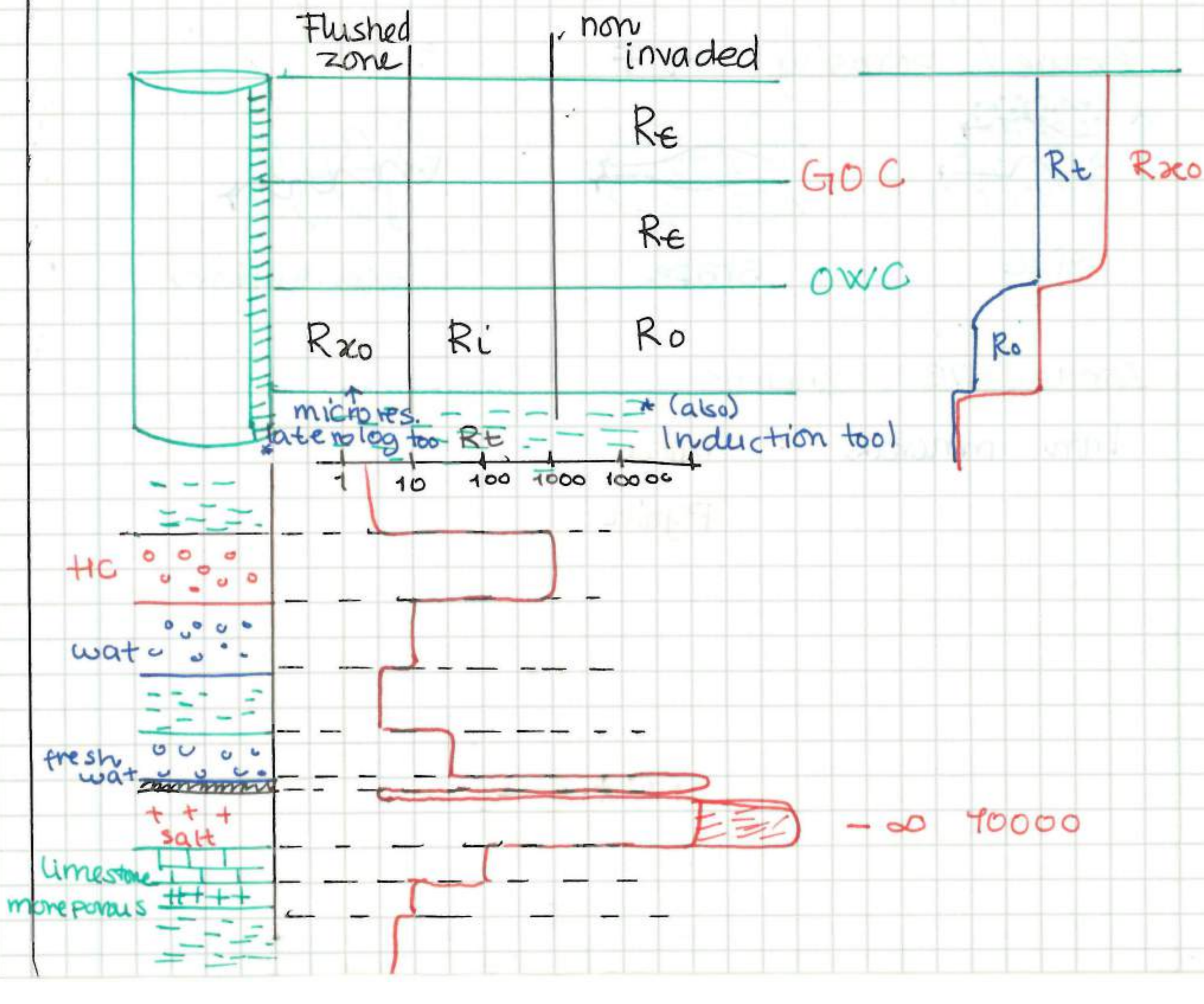
- Correct R_{weq} at T_f

Chart ④ => we find R_w at $T_f = 155°$ = 0,018 Ωm

Spontaneous Potential



Resistivity



Rt

- HC detection
- ϕ in water zone
- Sw in HC zone
- VShale
- Sedimentology
- fracture dectection
- HP Pressure zone

Rxo

- Better Rt ⇒ Sw estimation
- S_{HR}
- Gas correction for ϕ
- ϕ in water zone

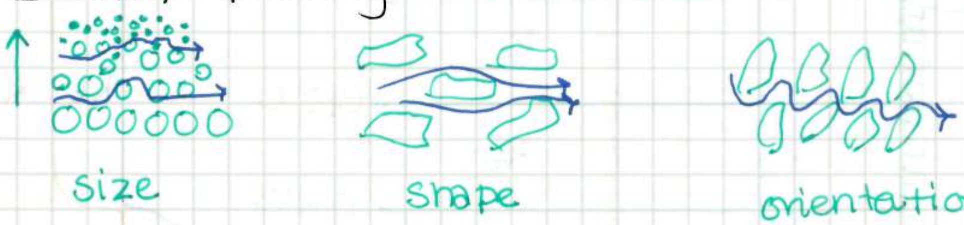
$$S_w = \sqrt{\frac{F \times R_w}{R_t}}$$

$$S_{HR} = 1 - S_{xo} = 1 - \sqrt{\frac{F \times R_{mf}}{R_{xo}(oil)}}$$

$$F = \frac{0{,}62}{\phi^{2{,}15}}$$

} Archie formula

Texture / porosity → F



conductive minerals

Iron minerals : mica
Pyrite

Resistivity logs

Produce a current into the formation and measure the response of the formation to the current.

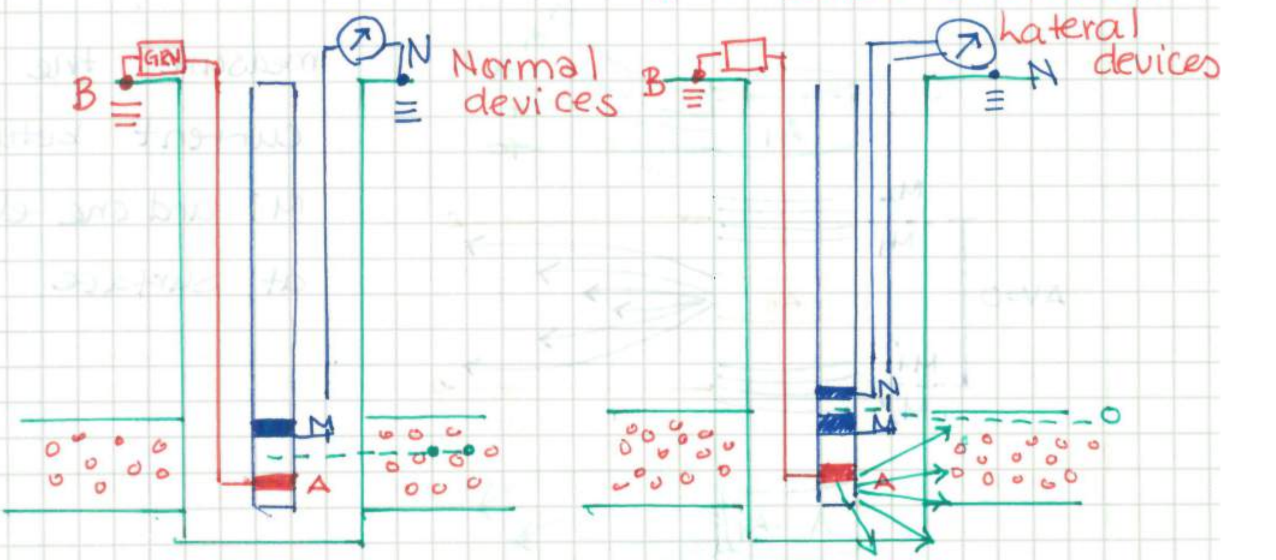
- Electrode / Laterologs ⇒ measure R
- Induction tools = measure conductivity

Depth of investigation

Flushed zone R_{xo}	Transition R_i	NON - invaded R_t
micro log (ML)	Short normal (SN)	Long normal LN
micro latero log (MLL)	Laterolog 8 LL8	Laterolog LL
		LL3
Proximity log (PL)	Spherically focused log SFL	LL7
Micro Spherically Focused log MSFL	Shallow LLS ILM	deep laterolog LLd
	Medium Induction log	Deep Induction log ILd

Laterologs

m : monitor electrodes
A : current electrodes



Rmf ≤ Rw

array induction tool AIT

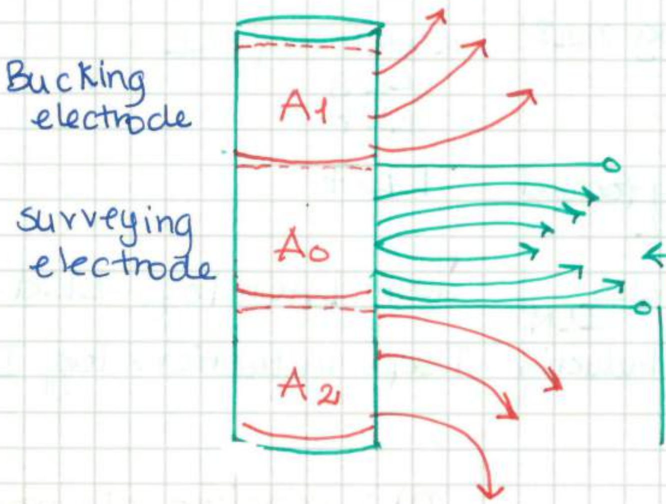
WBM

array LL

Focusing electrodes

→ less impact of bore hole shape and size.
→ control the path of the current i_0

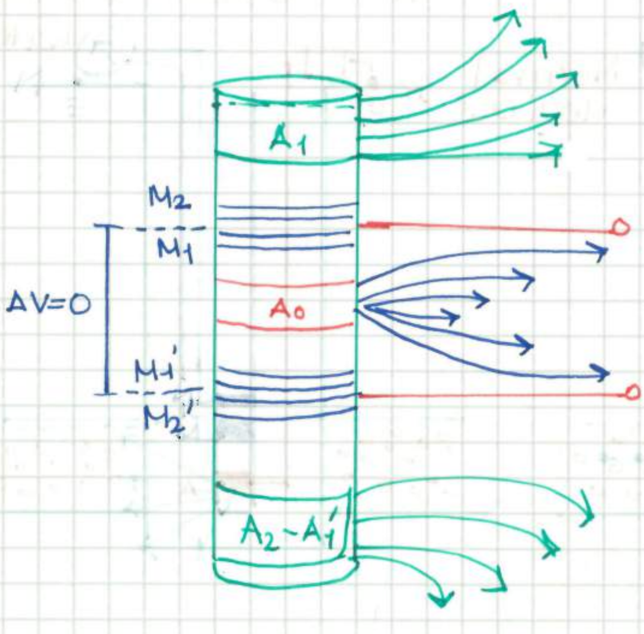
LL 3



A_1 A_2 adopted to potential of A_0 ⇒ the measured current to form resistivity

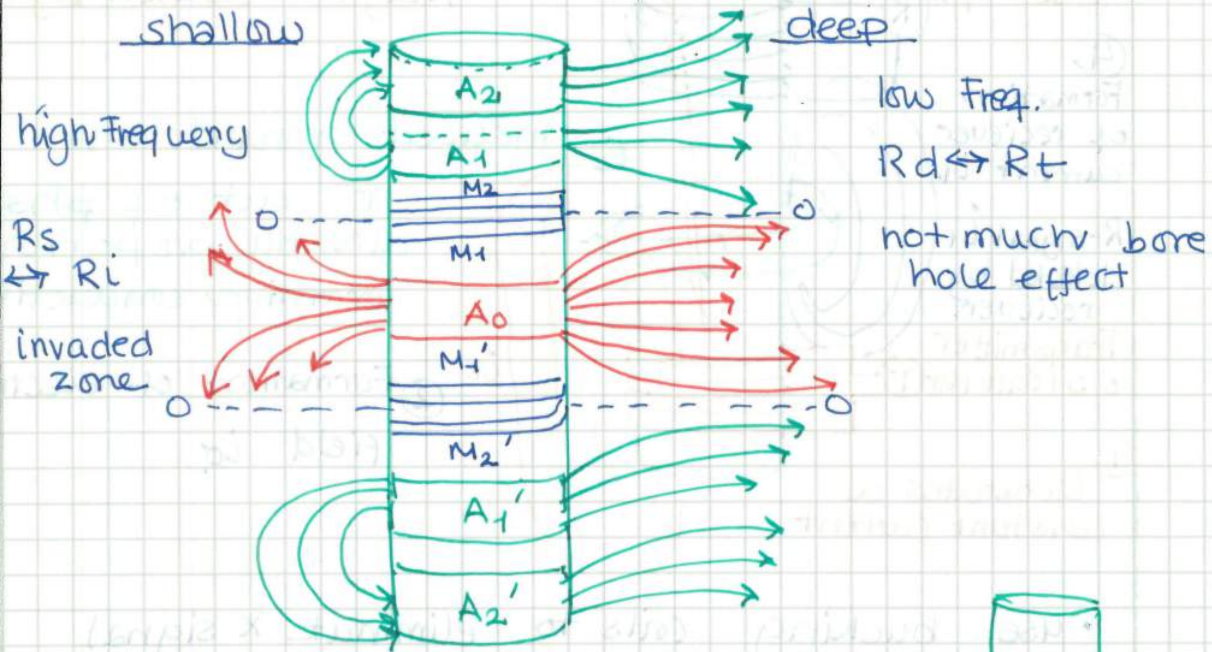
low frequency
10 - 100 Hz

LL7

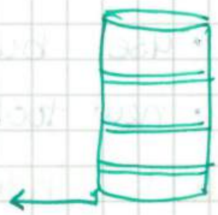


measure the current between Mi and one electrode at surface

- dual LL



- Spherically focused log SFL
- Array Laterolog

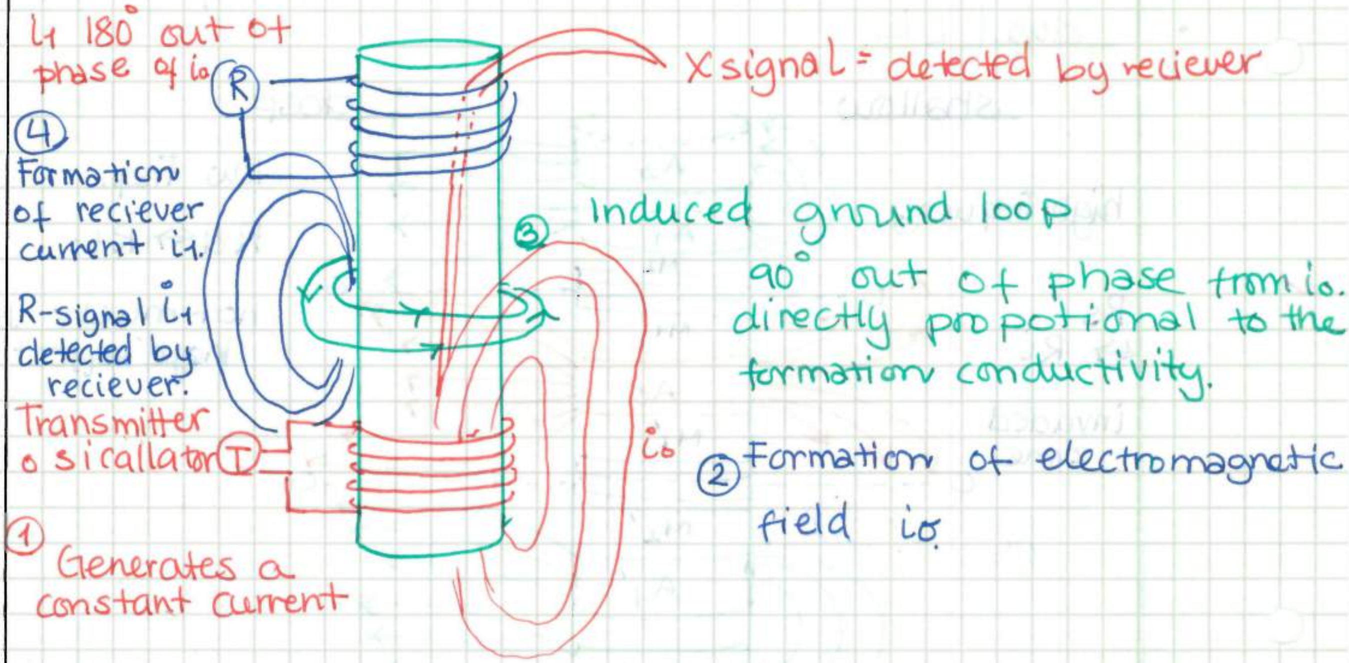


Multiple spacings ⇔ ≠ depth of investigation → numerous curves → processing to display few of them.

- Azimuthal Resistivity log ARI
  - oriented images 360°
  - deep investigation

Induction Logs

- measure conductivity and convert it into R.
- WBM + OBM



- use bucking coils to eliminate x signal
- new tools that can measure x signal

- dual Induction tool

  1T
  1T Bucking
  2 Recievers → deep 1-5m — Vertical Resolution 2,5m
  Shallow - 0,8 - 1,5 m — 1,5m

- Correction for invasion of mud filtrate
- Array Induction tool AIT

  1T
  8 Recievers
  ⇒ Create 28 raw R-curves
  Processing of the curves to determine invasion profile

  5 curves 10", 20", 30", 40", 60"
  2,5cm 2,3 cm
  Vertical resolution 1-2 m

LL

$R_{xo} < R_t$

$R_{mf} < R_w$

WBM

Induction logs

OBM

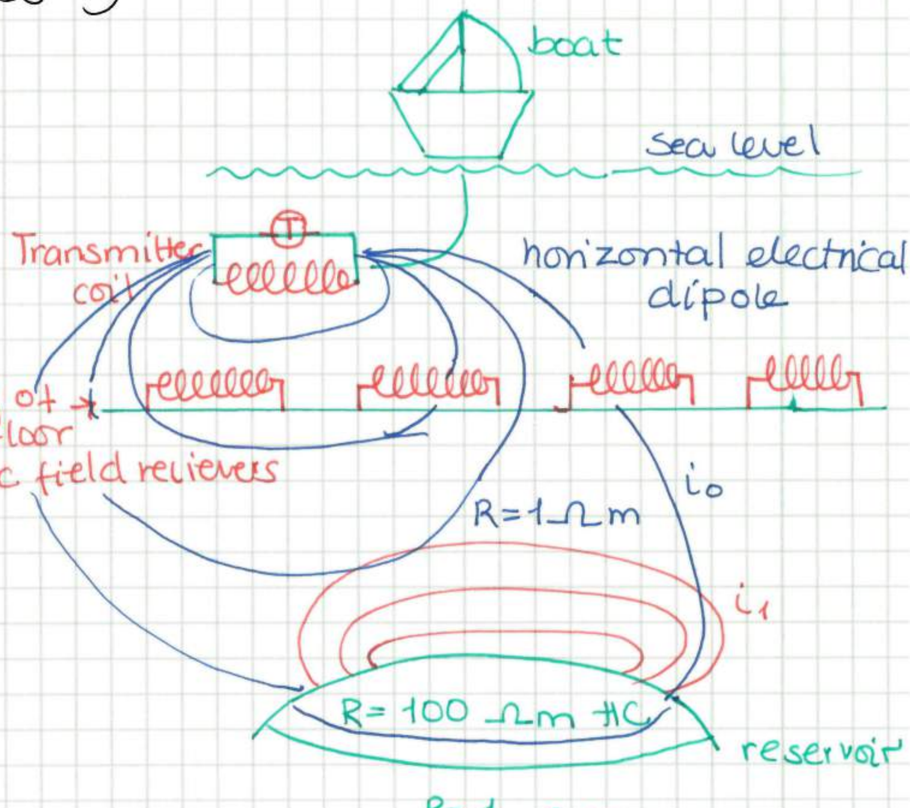
$R_{xo} > R_t$

$R_{mf} > R_w$

deep investigation

Sea bed logging

EMGS
(company)



i_1 = reflective energy / electromagnetic field from the subsurface

Geo steering

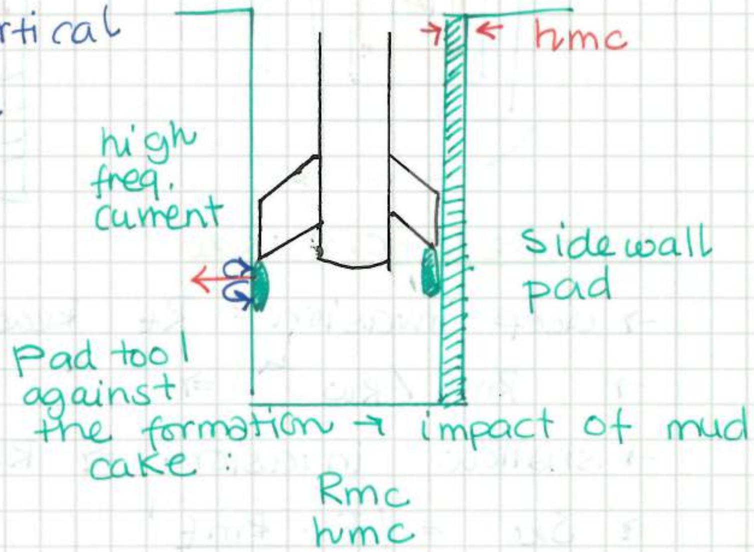
Maintain / direct a horizontal well into a thin geological layers. Sandstone

Contrast of R between Ss layer and the surrounding layers.

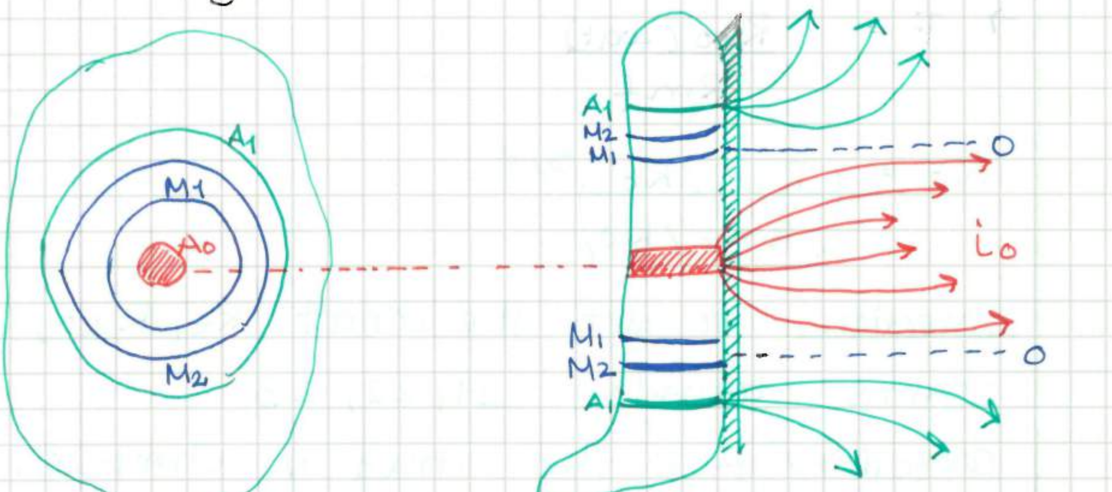
26,03 Micro resistivity log

→ look at R in flushed zone R_{xo}, R_{mf}
→ in addition of LL and IL
→ S_w, S_{HR} (S_{xo})

High freq. = micro depth investigation
good vertical Resolution.

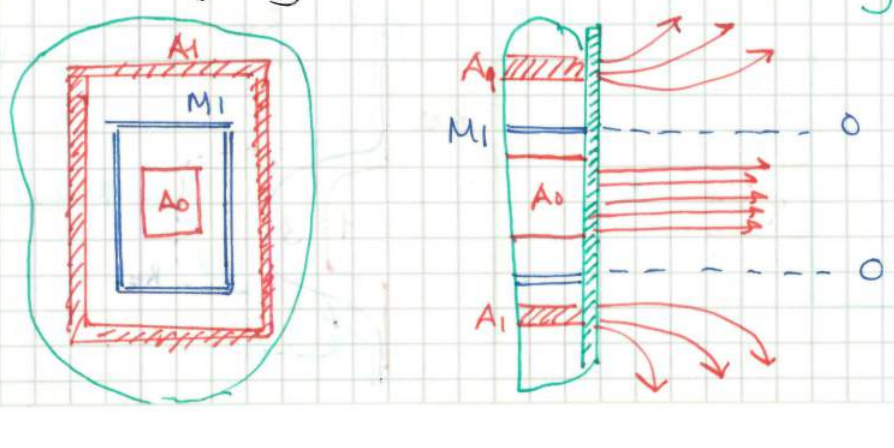


Micro laterolog MLL

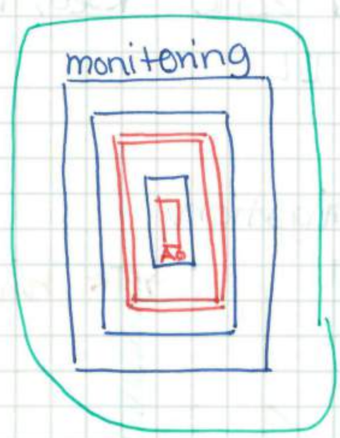


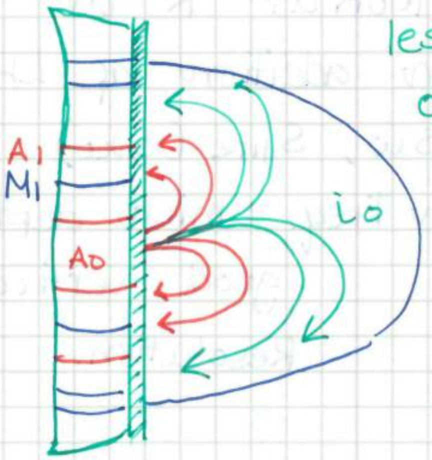
A_1 = Buking electrode

Proximity log



Microspherically focused log MSFL





less impact of mud cake
more used

Interpretation Rxo

→ deep invasion = Rt Reading affected by Rxo

→ Rmf / Rw ↗ ⇒ ↗

→ shallow invasion ⇒ Rxo by Rt

→ $S_{xo} = \sqrt{\frac{F \cdot R_{mf}}{R_{xo\ oil}}}$

→ $F = \frac{R_{xo\,(wat)}}{R_{mf}}$

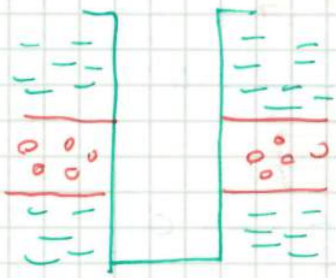
$S_w = \left(\frac{R_{xo} / R_t}{R_{mf} / R_w}\right)^{5/8}$

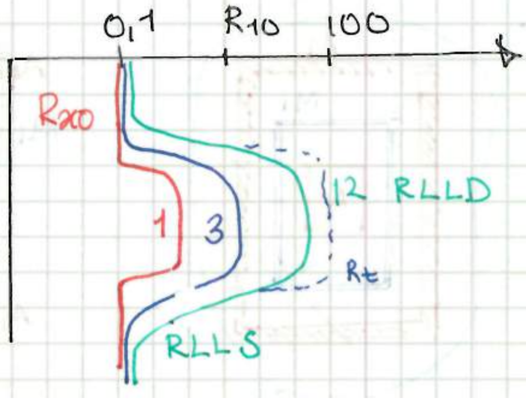
corrections to get the correct R_t, R_{xo}, di (invasion depth)

charts tornado 21, 22, 23

correction for the mud ⇒ Chart 20.

Chart 21 example





$\frac{RLLD}{RLLS} = 12/3 = 4$

$\frac{RLLD}{R_{xo}} = \frac{12}{1} = 12$

} chart 21

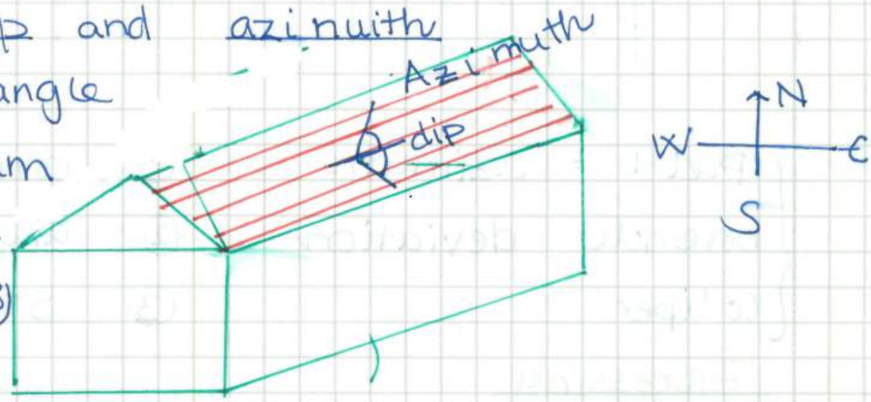
$\frac{Rt}{RLLD} = 1,52$ $Rt = 1,52 \times 12$

$Rt = 18,24$

Dipmeter

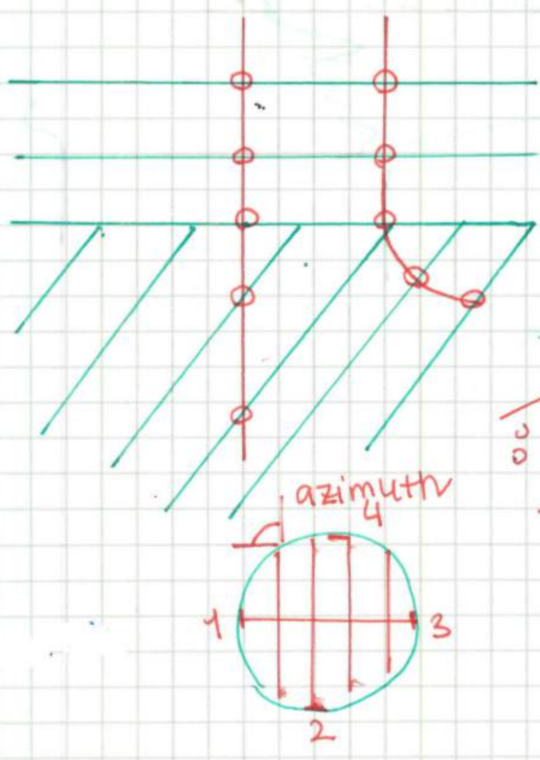
measure dip and azimuth

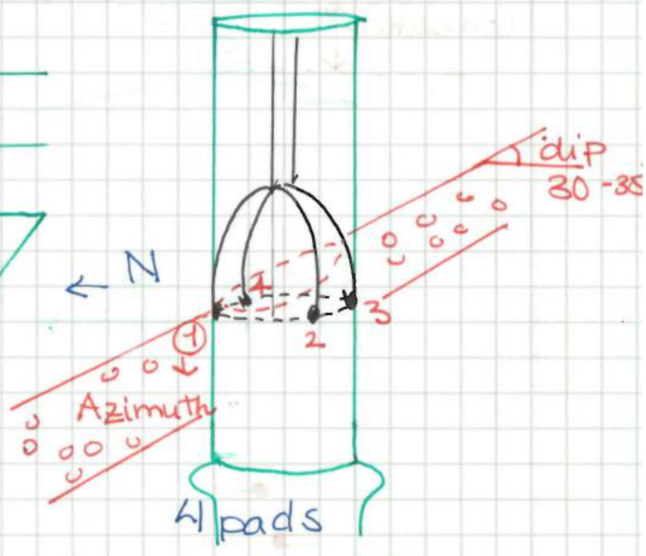
dip direction angle of the maximum inclination on the plane (0-90°)

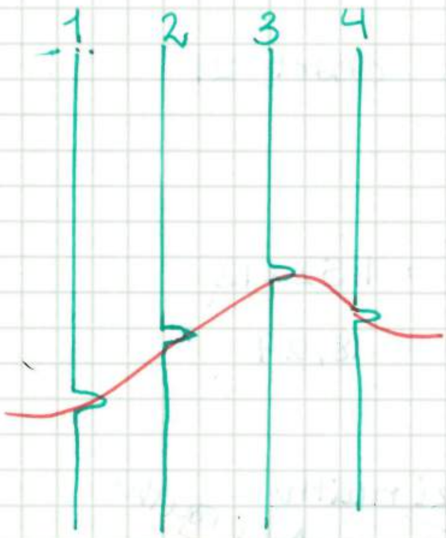


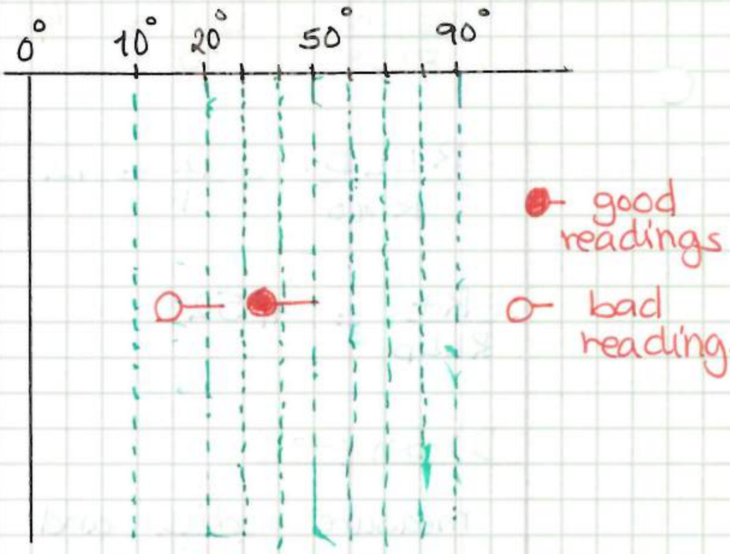
Azimuth

orientation of the plane according to the North [0, 360°] strike line = perpendicular line to dip.









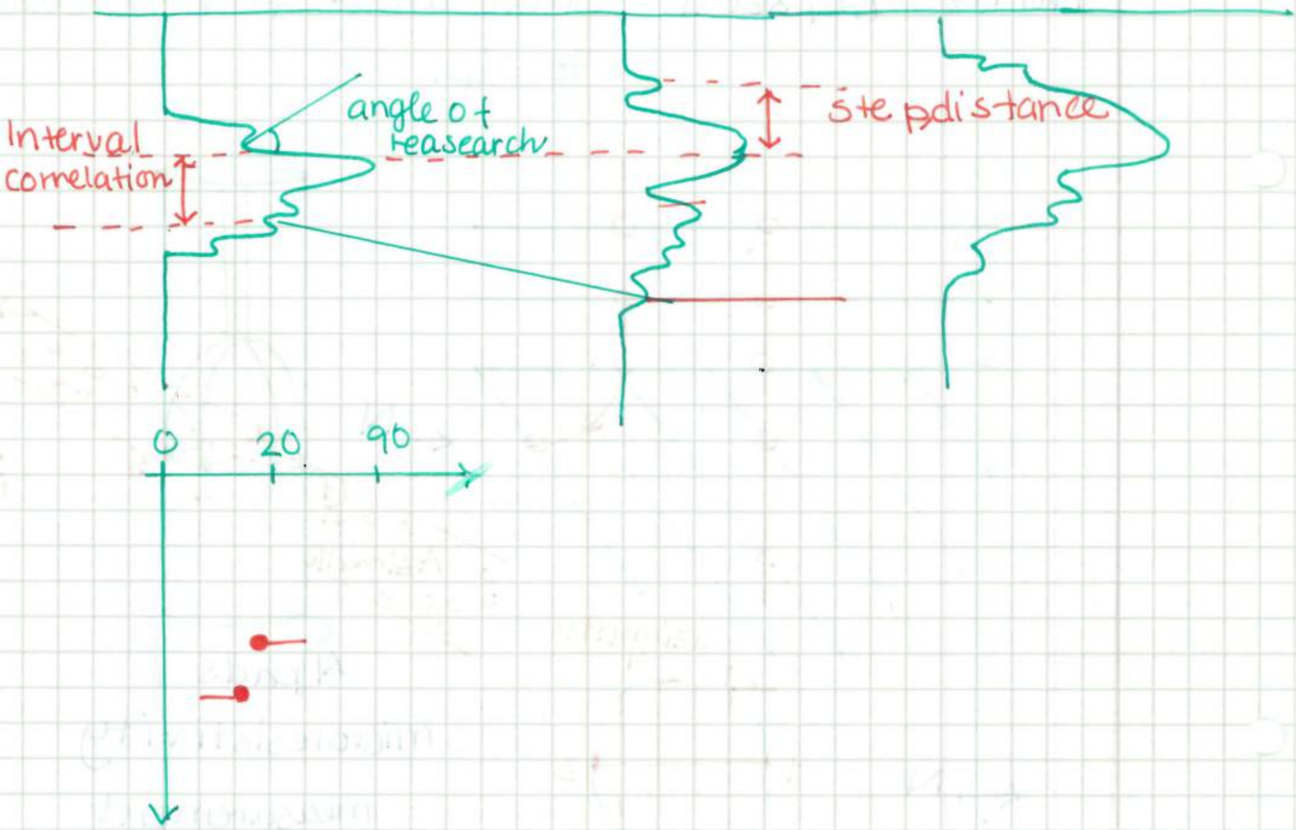
TADPOLE PLOT

- Pad 1 = azimuth
- borehole deviation
- caliper

① correlation interval
② angle of research
③ Step disance.

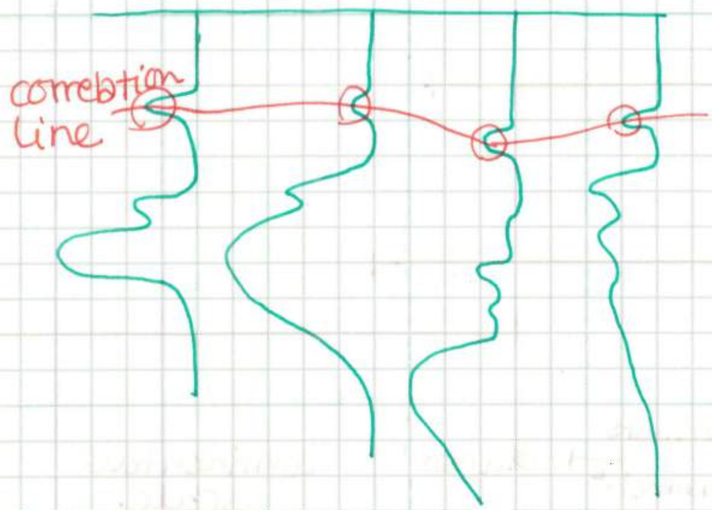
Processing

① fixed interval correlation :



② feature Recognition

try to correlate as will do the eyes.



Interpretation

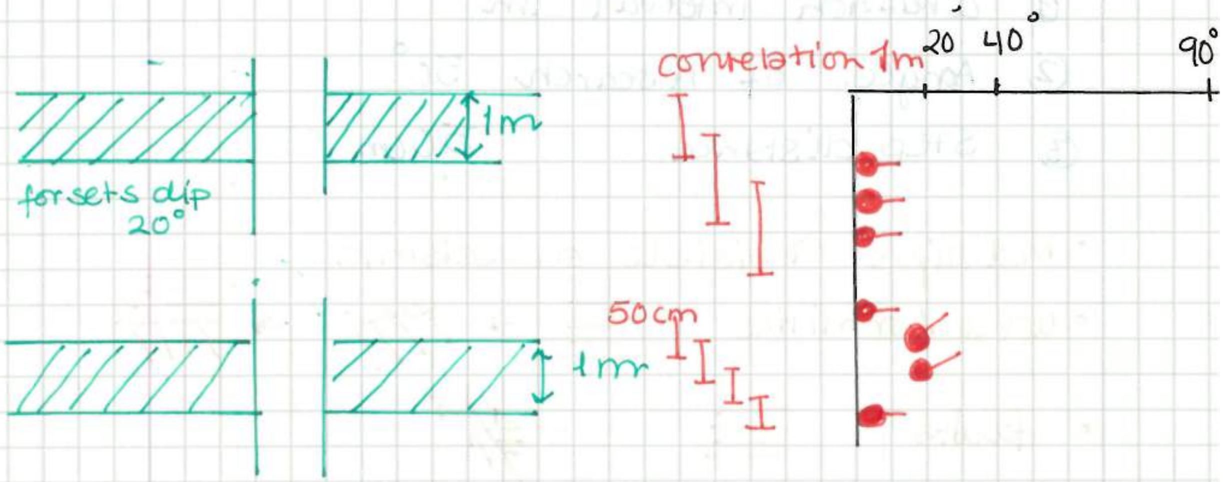
outcrop → geologist → choice → dips

dipmeter → tool → dips → petrophysist to choose

⇒ select and process in function of the structure/ features you are looking at

Sedimentary dips

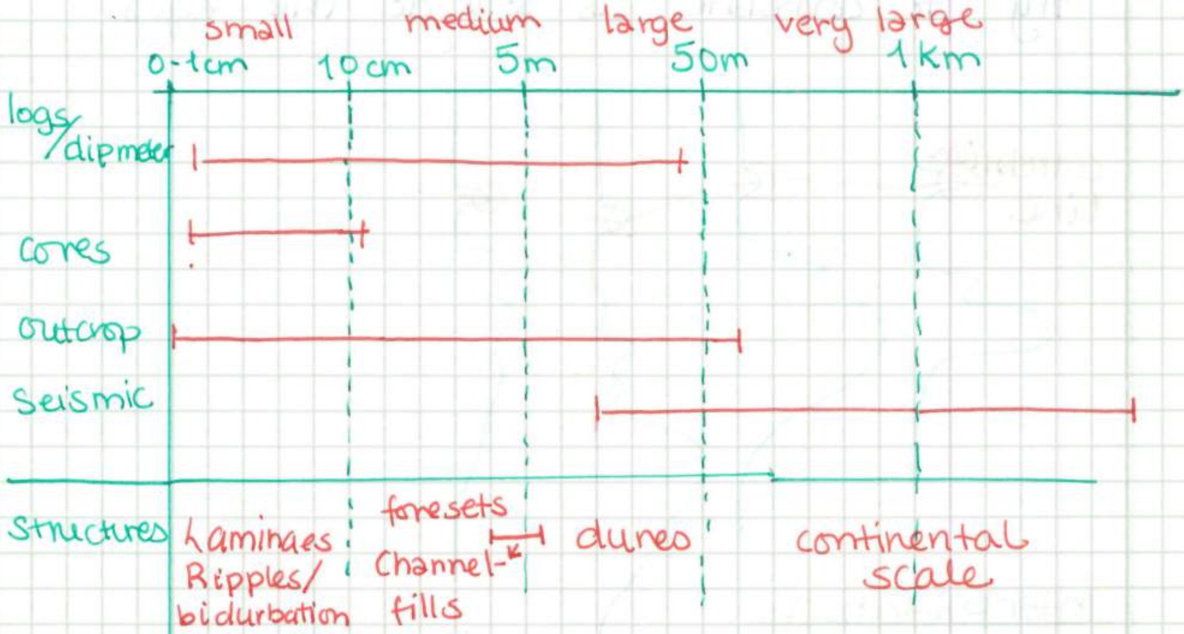
Lamination, cross beds, foresets.

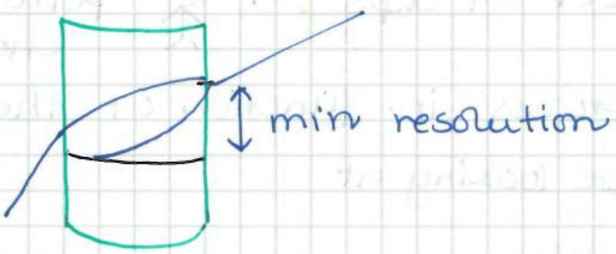


Small correlation interval 15cm

Step distacne 7-10 cm

angle 50°





Structural dips

1. correlation interval 1m
2. Angle of research 50°
3. Step distance 50cm

- bed dips → visible on seismic
- unconformities

- faults

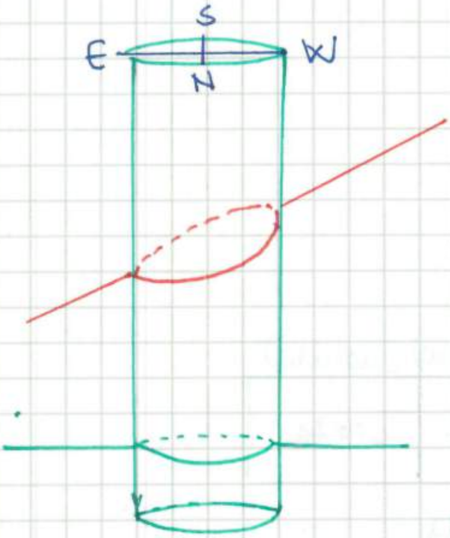
- fractures

27.03.14

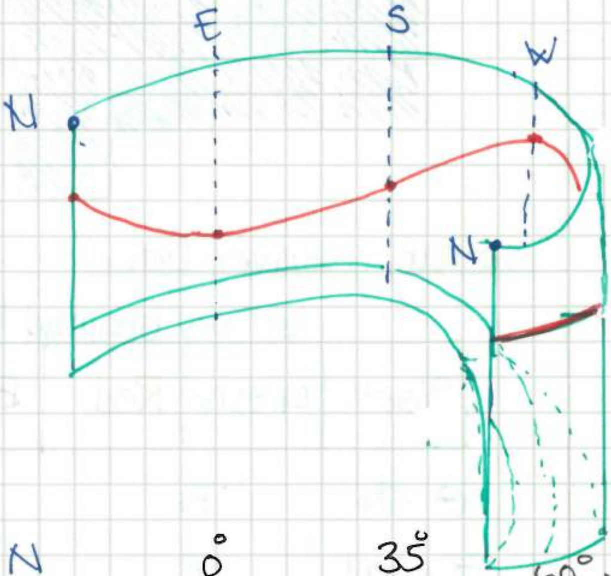
Image logs

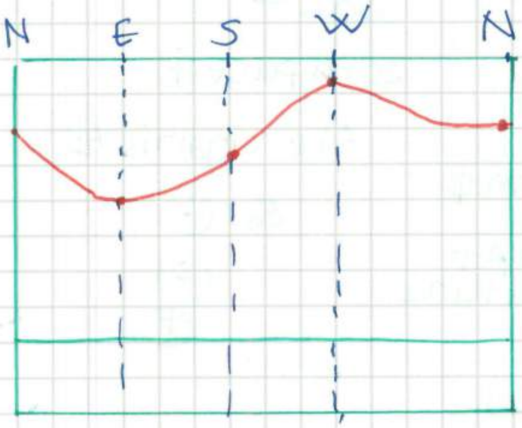
LWD ⇒ all logs can be converted to images
→ lower quality

WL ⇒ { electrical imaging / acoustic imaging
→ high quality.

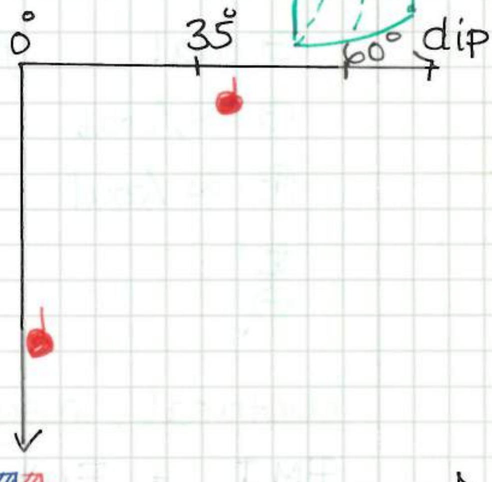


→

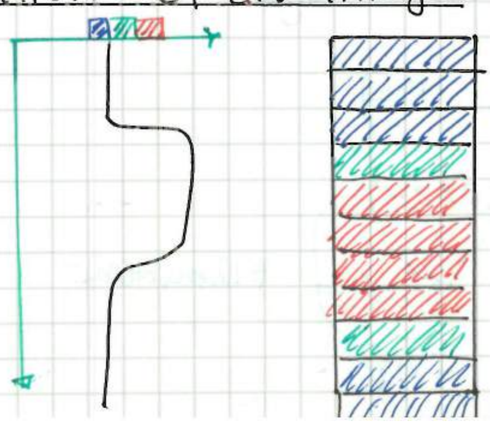


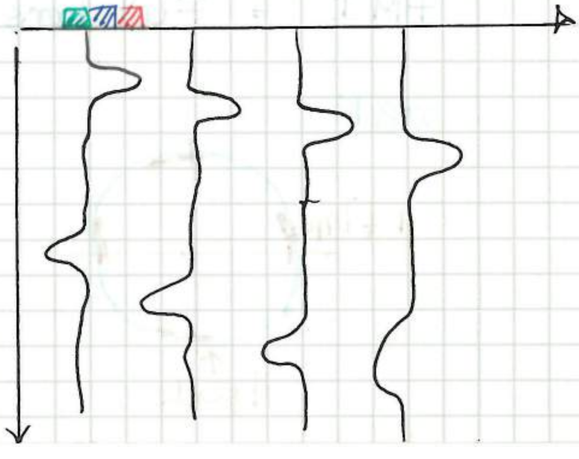


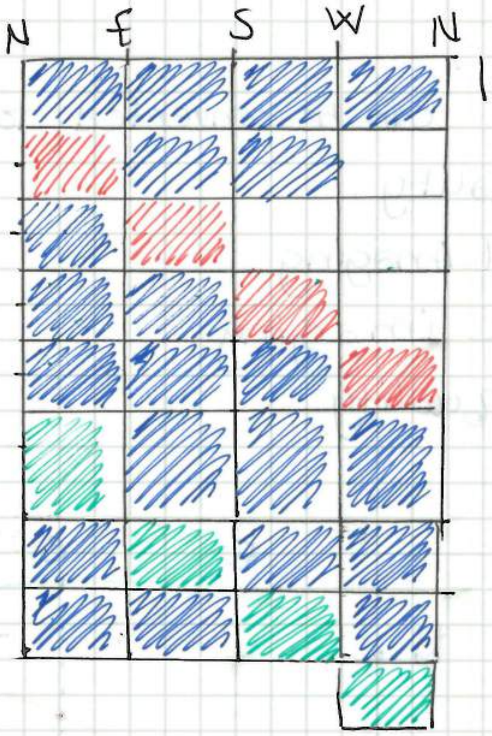
→



Creation of an image







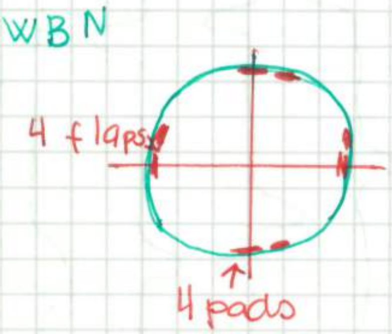
colour convention

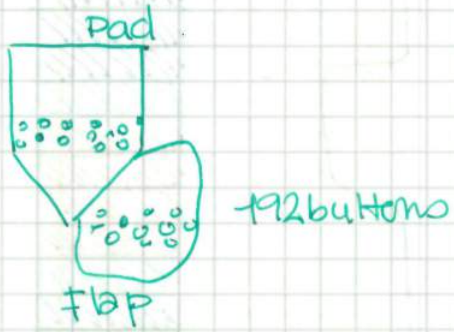
Black	Green (brown)	Red (organge)	Blue (yellow)	Perple (white)

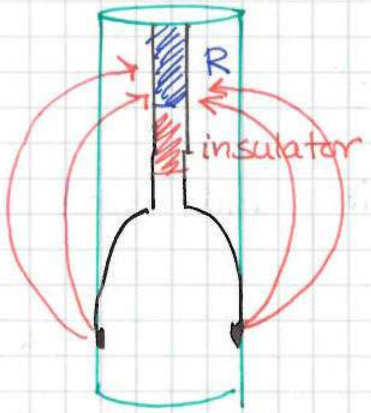
⊖ sh	R	HC coal ⊕
⊖ coal	ρ	compact ⊕
⊖ ss/coal	GR	sh organic ⊕
⊕ ss/coal	Neutron ϕ	Ss ⊖
⊕	sonic Δt	⊖
⊖	Amplitude	⊕

electrical imaging WL

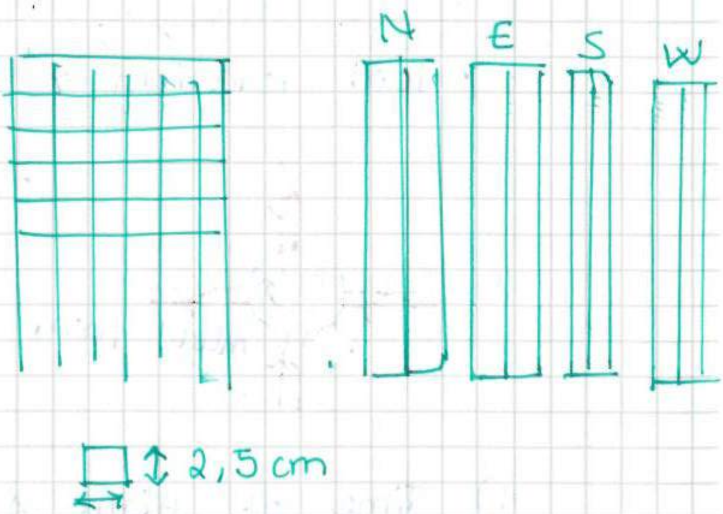
FMI = Full bors Micro Image





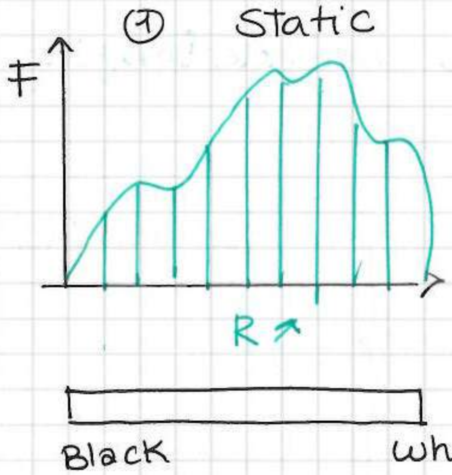


high frequency



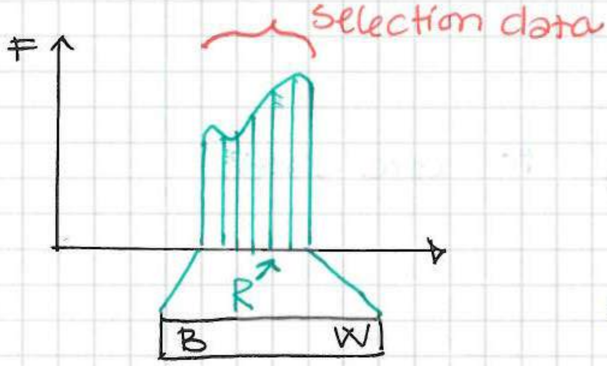
Processing

① Static



entire well

② Dynamic



enhance the details

LWD

RAB = resistivity at bit geovision

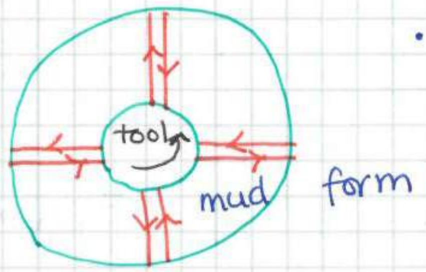
different depth of investigation

shallow	medium	deep
2,5 cm	7,6 cm	12,7

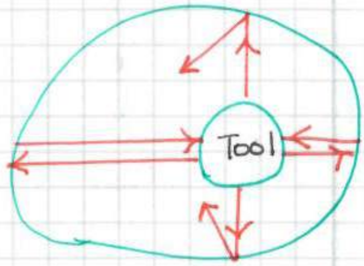
vertical resolution 5–10 cm

Acoustic imaging WL

- tool rotating ⇒ 360°



- emits and record sound waves



1) Time of flight Δt
2) Amplitude of the wave

CBIL = circumpherencial borehole imaging log

LWD

- density imaging
- Gamma Ray imaging
- Neutron porosity
- Resistivity
- Sonic

} geosteering

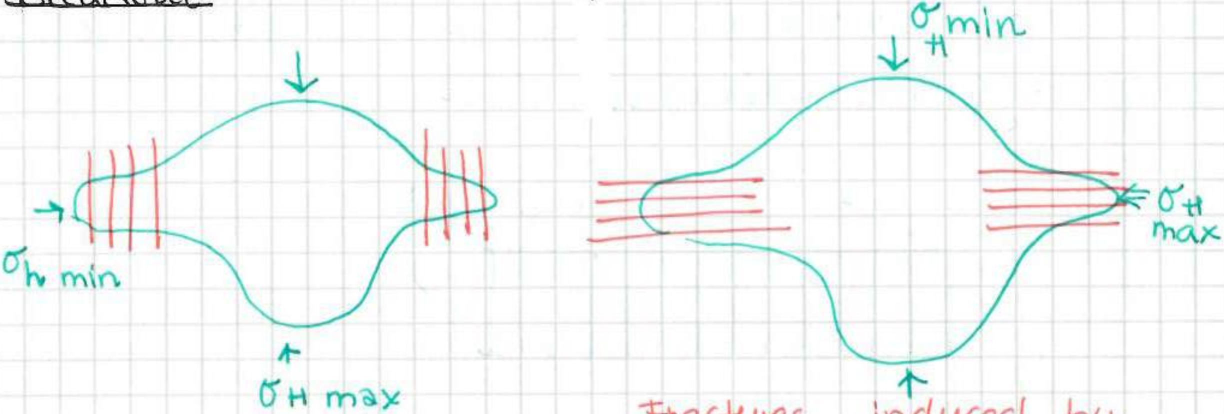
Interpretation

- dip + azimuth
- fractures
- complementary to core data
- Sedimentary
- structural

acoustic image	resistivity
360° all muds	20 % - 90 % coverage WBM
good sensitivity to fracture. borehole fractures breakouts ←	higher resolution ⇒ def. of small details thin beds Contrast acoustic impedance.

Natural Fractures	Drilling induced
① crossing entire borehole	① only in one section under stress
② highly irregular	② Regular
③ geometrically unrelated to borehole	③ Related to the borehole shape
④ Not related to current stress	④ Related to – breakouts
⑤ will not envolve	⑤ change with time
⑥ visible in cores	⑥ Not
⑦ semented or be fulled with hydrocarbons	⑦ Never be rafated to sement or HC.

Breakout

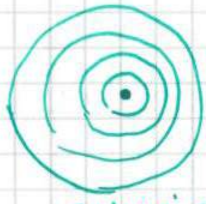


Fractures induced by drilling.

1/4 Sonic tool / acoustic log

measure the formation capacity to transmit sound waves.

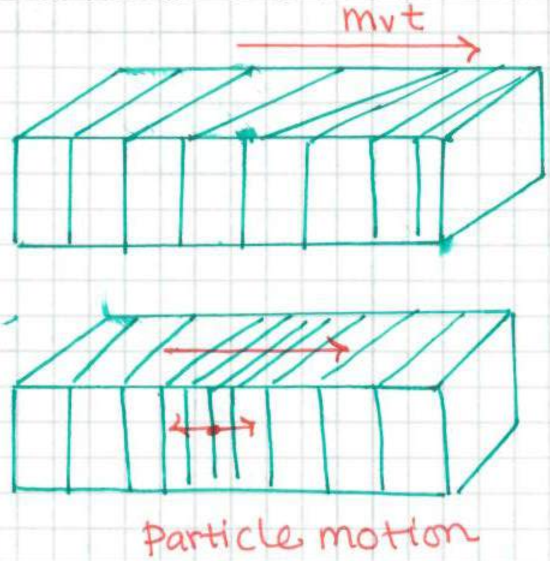
- compressinoal wave P
- Shear wave S
- Stoneley wave - surface



spherical wavefront

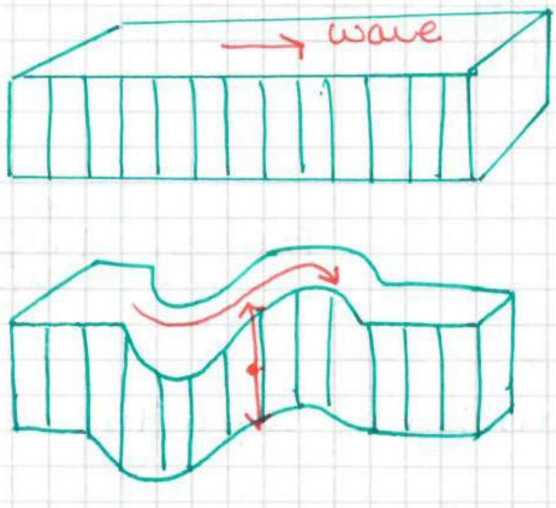
① Compressional waves - P wave (primary)

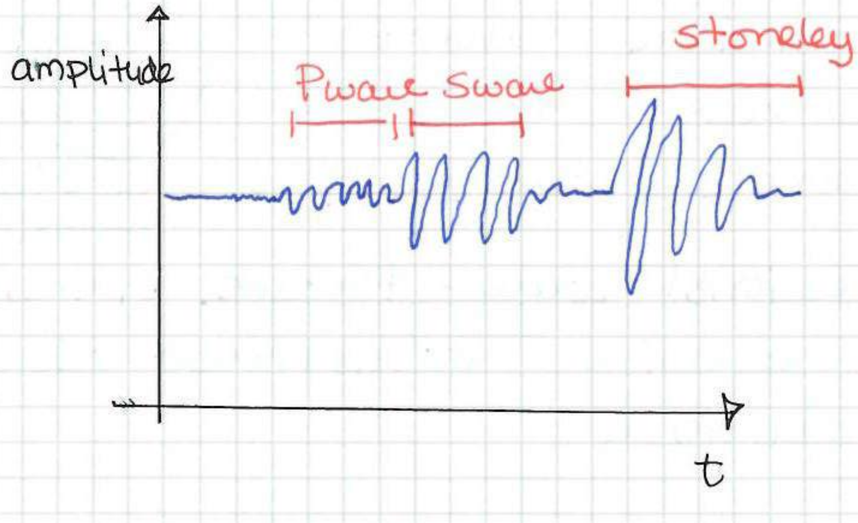
- 1st to arrive - travels through solids liquid
- low amplitude



② Shear wave S wave (secondary)

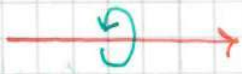
- slower than P-wave
- only in solids
- high amplitude.

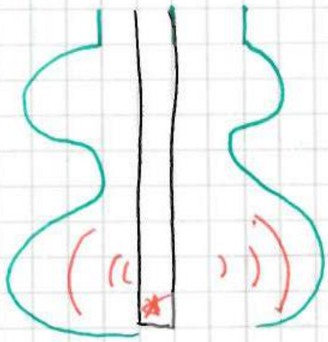




③ Staneley wave St wave (surface)

- tube wave
- low energy - slow
- high amplitude
- depends on frequency

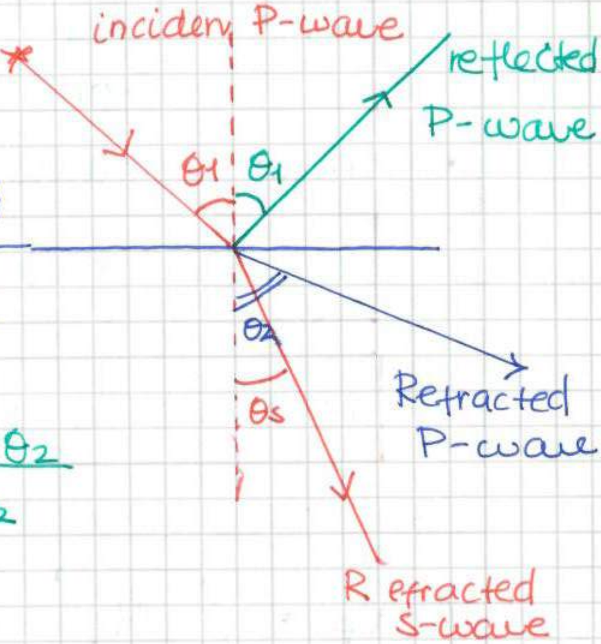




Snell's law

medium 1 : V_{P1}, V_{S1}, ρ_1

medium 2 : V_{P2}, V_{S2}, ρ_2



$$\underset{\text{ray path}}{p} = \frac{\sin \theta_1}{V_{P1}} = \frac{\sin \theta_2}{V_{P2}}$$

$$= \frac{\sin \theta_s}{V_{S2}}$$

Theory of elasticity

In seismic propagation, rocks are considered to be elastic.

- deformed
- Return to initial shape
- The deformation is $\propto$ to the stress applied on the object.

Hook's law

$$\underset{\text{stress}}{\sigma} = C \cdot \underset{\text{strain}}{\varepsilon}$$

C : elastic tension.

elastic properties

- Compressional modules M

$$\sigma_{axial} = M \cdot \varepsilon_{axial}$$

- Bulk modulus K

incompressibility = Resistance of the rock to change in volume

$$K = -\frac{P}{\varepsilon_{vol}} \quad \text{(pressure)}$$

- Shear modules μ

$$\sigma_{shear} = 2 \cdot \mu \cdot \varepsilon_{shear}$$

$$M = K + \tfrac{4}{3}\mu$$

seismic velocity

$$\begin{cases} V_P = \sqrt{\dfrac{M}{\rho}} = \sqrt{\dfrac{K + 4/3\,\mu}{\rho}} \\ V_S = \sqrt{\dfrac{\mu}{\rho}} \end{cases}$$

Acoustic impedance

$$Z_P = V_P \cdot \rho$$

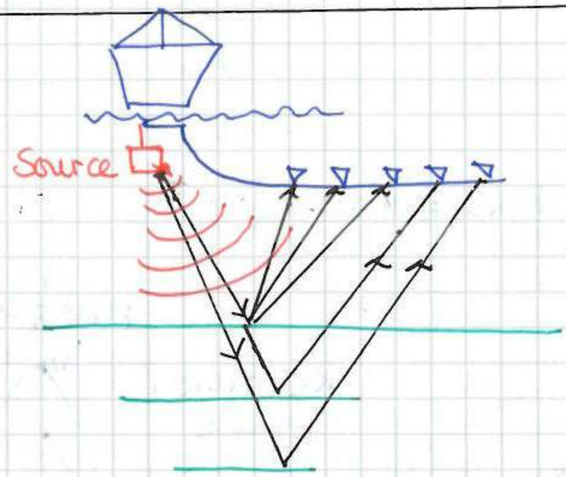
shear Impedance $Z_S = V_S \cdot \rho$

Seismic Reflection

⇒ define the reflection between 2 medium by the reflection coeffisient

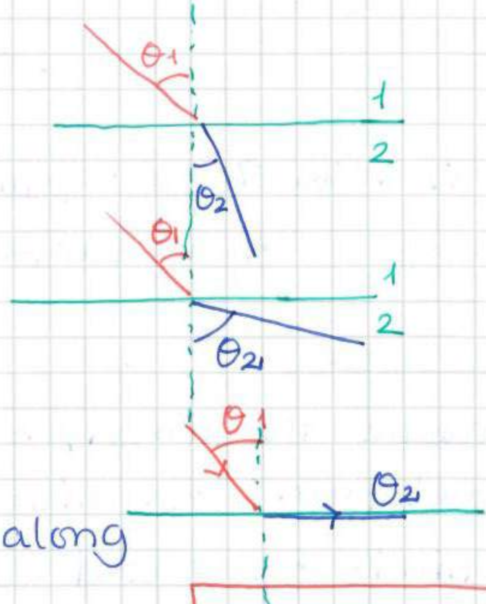
Relative change in acoustic impedance

$$R = \frac{Z_2 - Z_1}{Z_1 + Z_2}$$



Record { travel time
         amplitude.

Seismic Retraction



① $V_2 < V_1$

$\theta_2 < \theta_1$

② $V_2 > V_1$

$\theta_2 > \theta_1$

③ $V_2 >> V_1 \Rightarrow \theta_2 = 90^\circ$

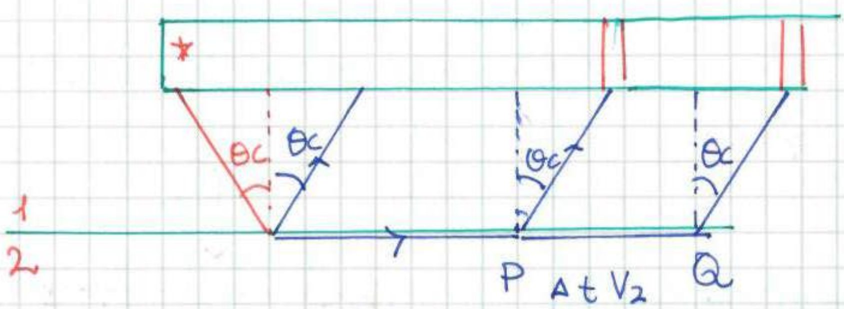
Retracted wave travels along the interface.

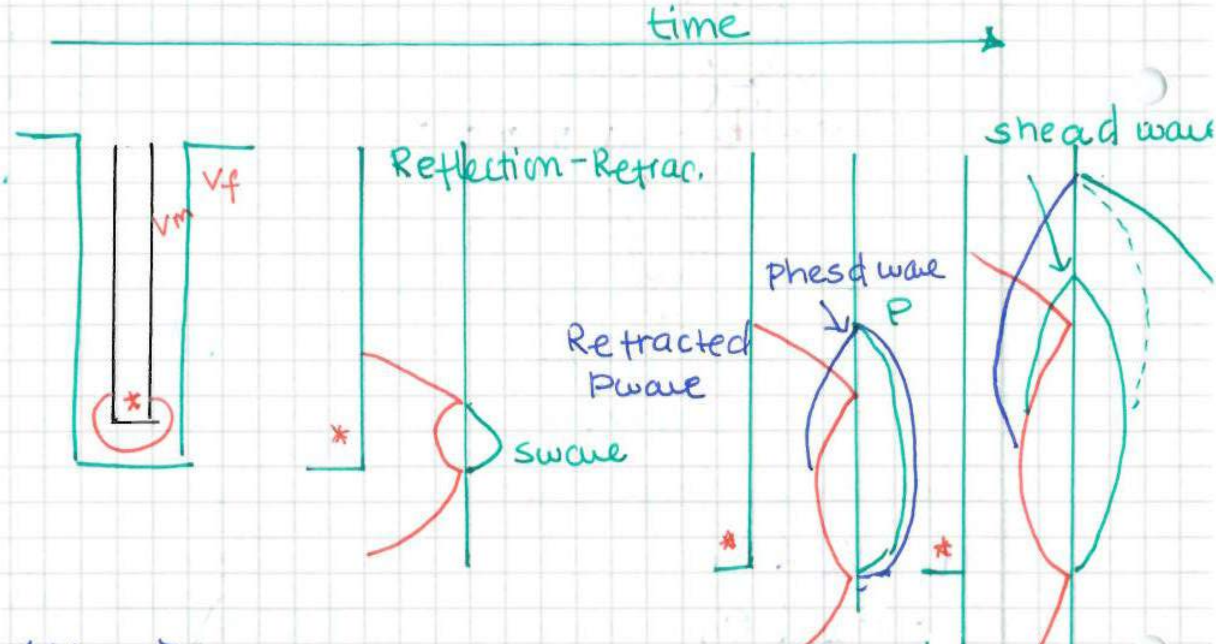
Critical angle $\theta_1 = \theta_c \Rightarrow$ $\sin \theta_c = \frac{V_1}{V_2}$

$\theta_1 > \theta_c \Rightarrow$ cannot apply snell's law

Head waves

waves retracted at critical angle:





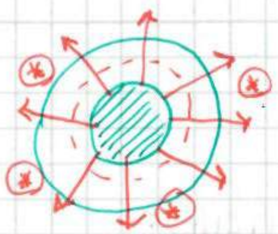
Vs < Vm ⇒ slow formation
⇒ no surface Swave refraction.

<u>Sonic tools</u>

measure the times / slowness of sound pulse to travel from transmitter to reciever.

3 kinds of sound sources.

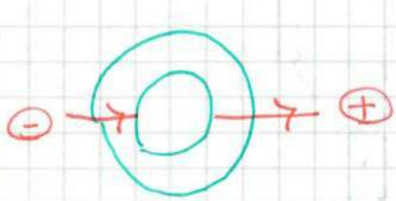
① <u>monopole source</u>



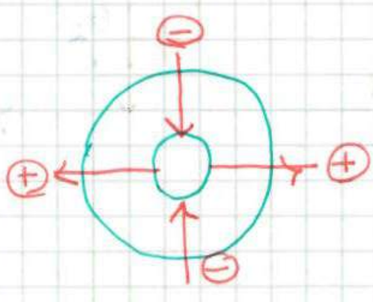
Propagation of Pwave
slow formation → no swave.
+/* compression
− delation / extension.

② <u>Dipole source WL</u>

generate strong S wave = flexural wave



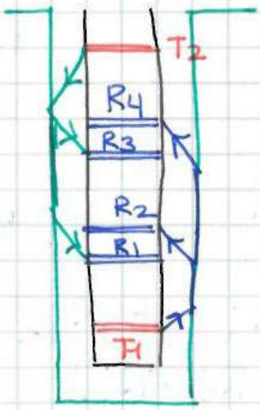
③ <u>Quadraupole LWD</u>



Older tools (1985)

BHC

Borehole compensated Sonic tool



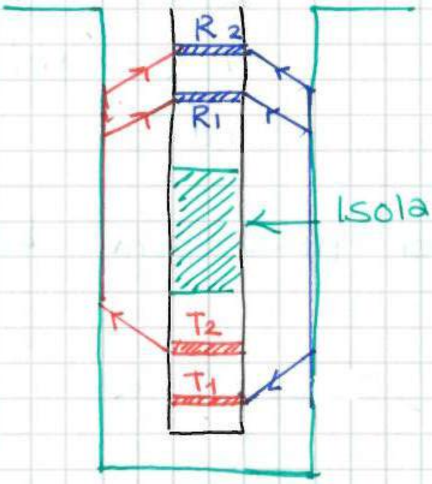
slowness ft / μs or μs/m

$$\text{Slow } 1 = \frac{R_4 - R_2}{t_{R4} - t_{R2}}$$

$$\text{slow } 2 = \frac{R_1 - R_3}{t_{R1} - t_{R3}}$$

} average

LSS Long spacing sonic tool



larger space ⇒ better reading

vertical resoultion 60cm

• WL Sonic tool

Dipole source, array of recievers

{ 18 - 13 re cievers
1 T monopole
1 T dipole

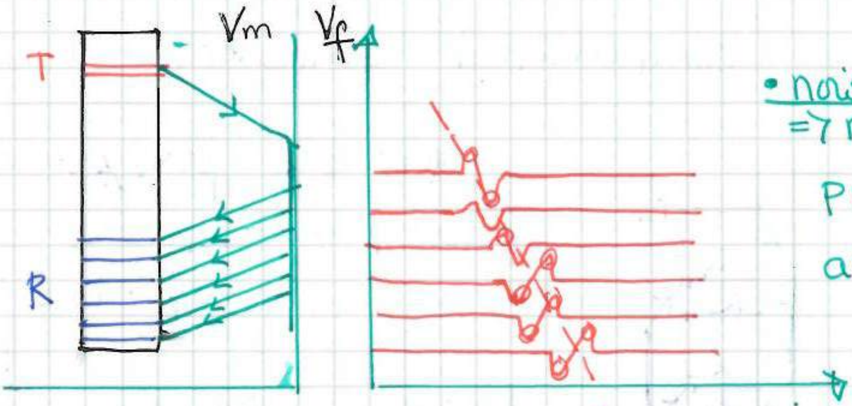
V_{P}, V_s, V_{ST}

DSI Dipole Shear Imager

⇒ 512 readings

⇒ midpoint processing

Sonic Scanner



- noise
=> not able to pick same t of arrival for each reciever.

$$\text{slowness} = \frac{\sum_{ij}(\text{difference } tR_i - tR_j)}{\sum_{ij}(\text{difference } R_i - R_j)} \quad \mu s/ft \ (m)$$

DTC = slowness Pw

DTS = slowness Sw

+ noise.

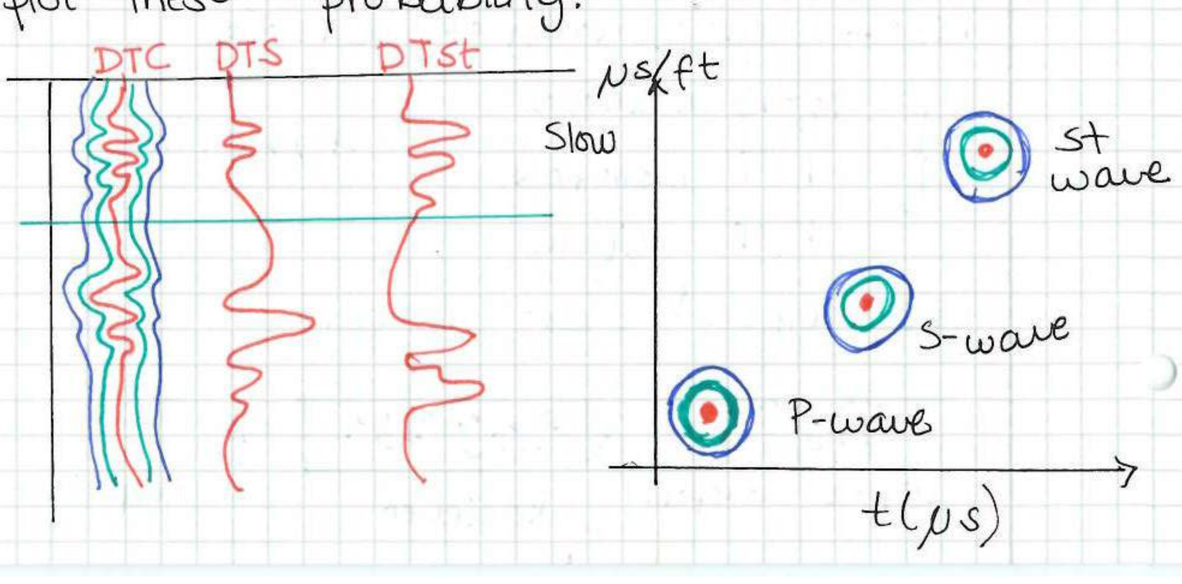
- use coherence algorithm to process => probability of the event. *

LWD most challengding adoptation

- distinguish the sound pulse from background sound.
- acoustic isolation btw T-R

quadraupole => Sonic Vision tool

02/04 * plot these probability.



Application

① Porosity

$\Delta t = \frac{1}{V}$ µs/ft

Wyllie time average equation P-wave.

$$\frac{1}{V_p \log} = \frac{\phi}{V_{fluid}} + \frac{1-\phi}{V_{matrix}} \Leftrightarrow t_{log} = \phi t_f + (1-\phi)\Delta t_{ma}$$

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fluid} - \Delta t_{ma}}$$

DTC

• compute DTS

$\Delta t_{shear} = 2{,}72 \cdot \phi + \Delta t_{sh^{ma}}$

⇒ not affected by gas effect.

⇒ over estimation ϕ_s when gas.

② Formation strength or acoustic formation factor

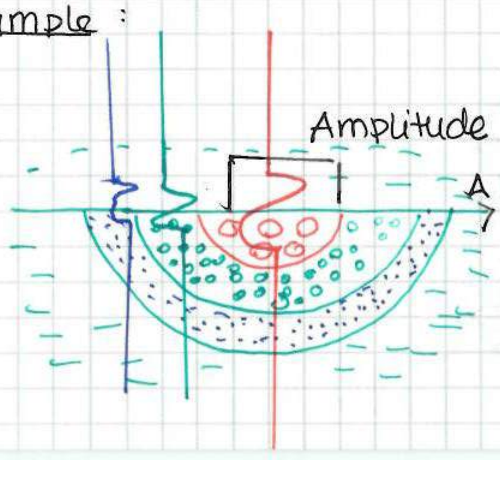
B_{cp} = chart ⑥

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_{fluid} - \Delta t_{matrix}} \times \frac{1}{B_{cp}}$$

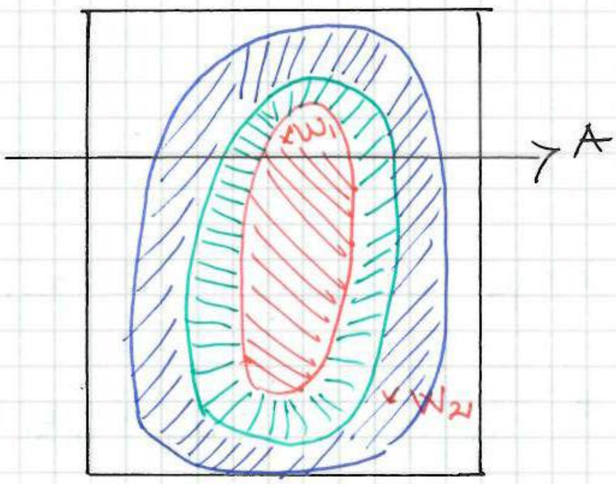
③ Seismic amplitude - ϕ (lithology)

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$

example :



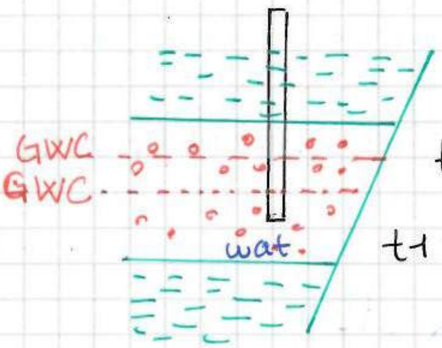
high ϕ — high amplitude
medium ϕ
low ϕ — small amplitude



Amplitude map

④ 4D-seismic

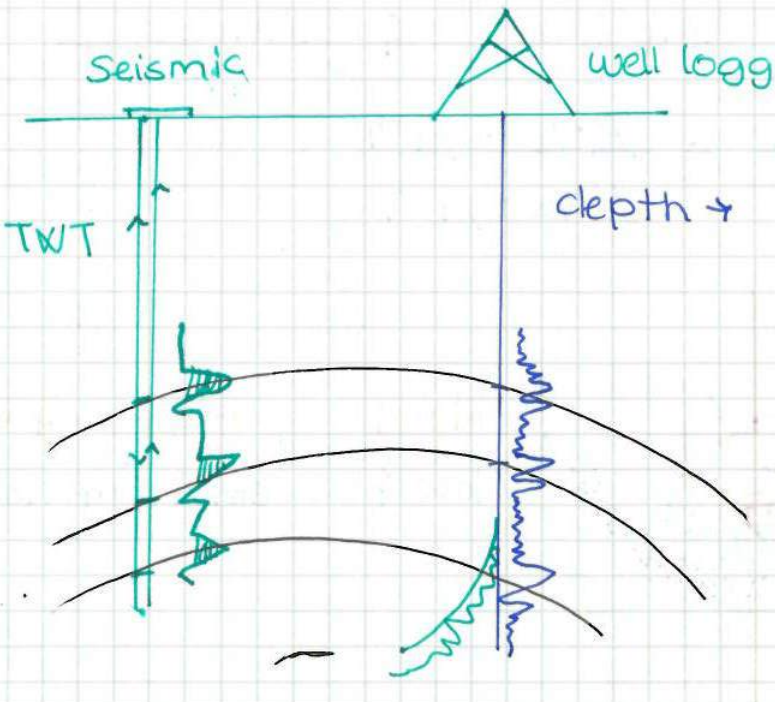
3D seismic + time



t_2 = 2nd investigation

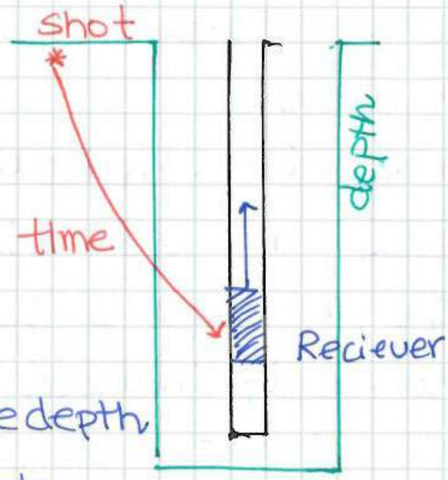
t_1 = 1st seismic investigation.

⑤ time - depth conversion



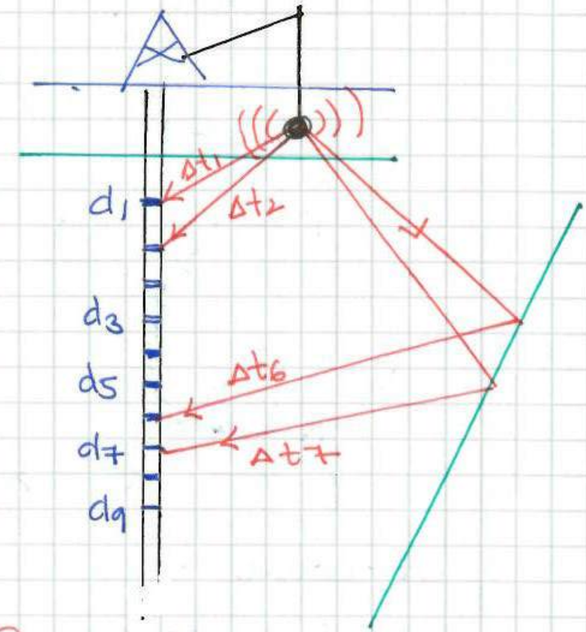
depth → measured depth ≠ vertical depth.

- Check shot data

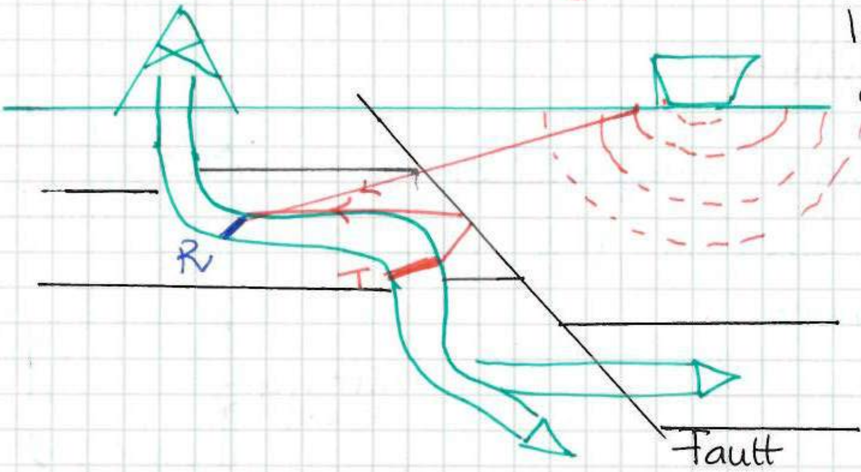


Time depth table.

- vertical seismic profile (VSP)

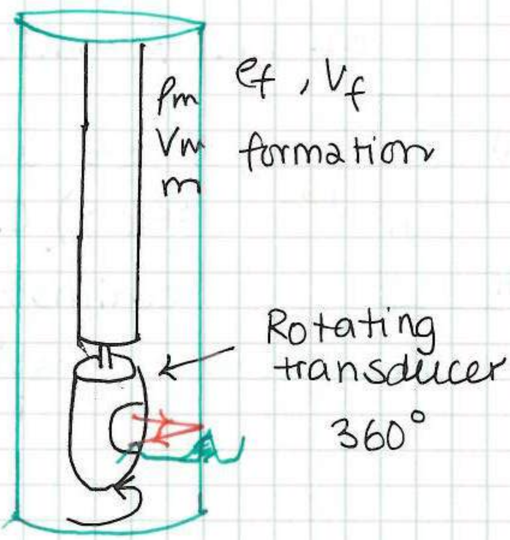


⑥ Seismic while drilling



look ahead during geosteering

⑦ Image logs WL

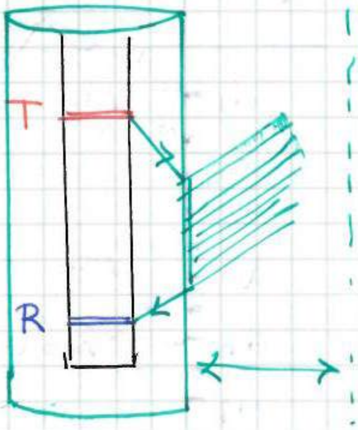


measure =
{ time of fligh
  amplitude

- use for fractures
  breakouts

- need strong difference in acoustic impedance.

(8) Fractures



Pwave - Swave

{ Δt same
decrease in amplitude

Pwaves → avoid void space

Φs → compare Φ density log to see if induced fractures.

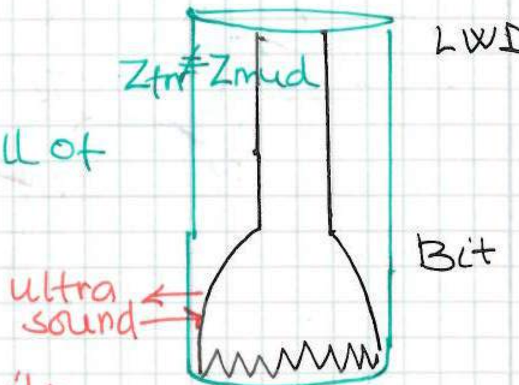
St - wave ⇒

sensible to open fractures at low frequencies.

(9) Caliper

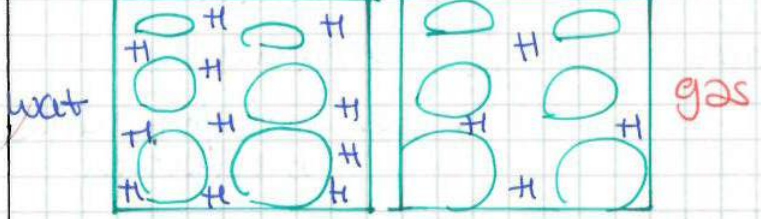
very high frequncies.

- Reflected on the wall of borehole.



(10) Gas effect on porosity

Gas = low density ⇒ decrease the apparent ρ of the formation

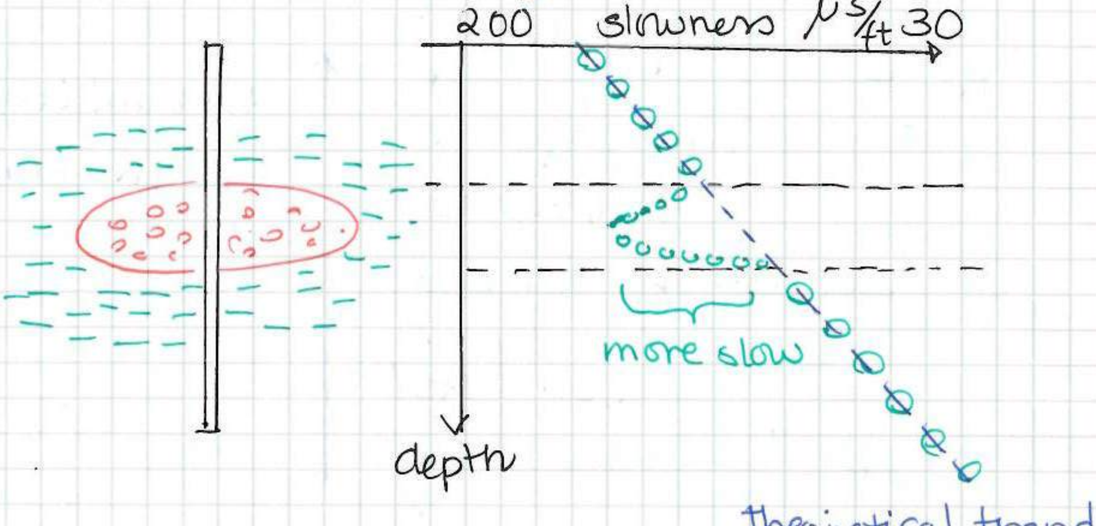


⇒ Δt increase (more slow) Φs over estimated

H: hydrogen

Flushed zone - still 15% gas.

(11) Overpressure (region)



10m } ≈ 1 bar

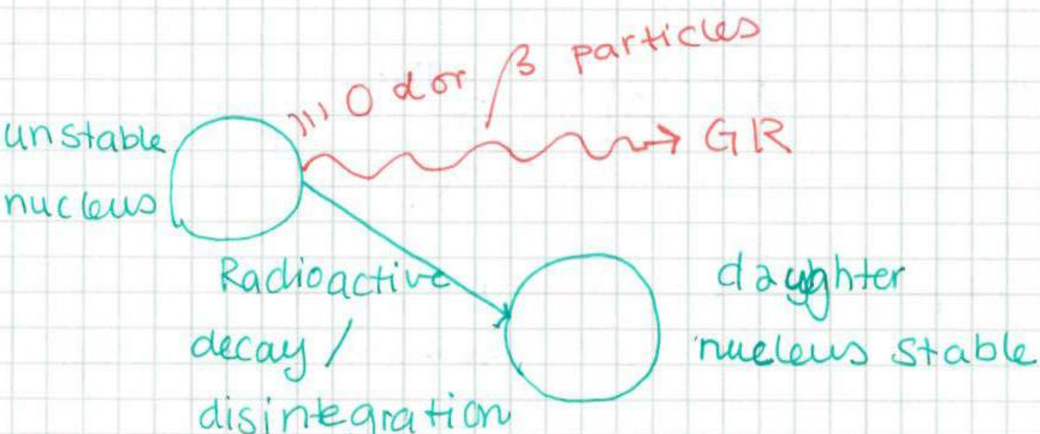
03.04. **Gamma ray** – shale log

Record the natural radioactivity of the formation

Uranium U
Thorium Th
Pottassium 40K

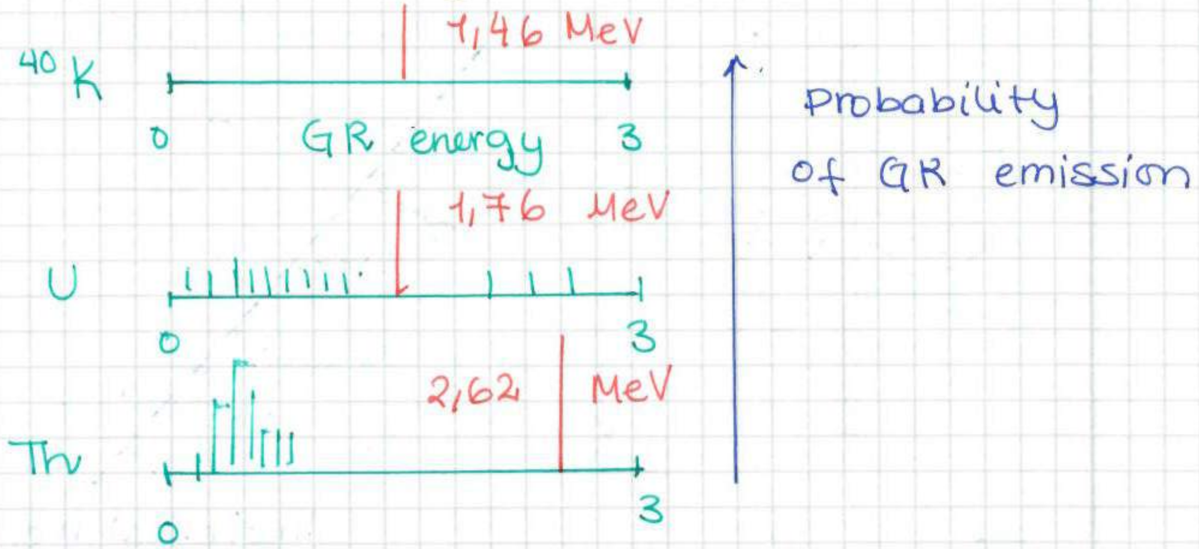
simple GR tool ⇒ total count radioactivity
spectral GR ⇒ volume fraction of each element

Natural GR emission



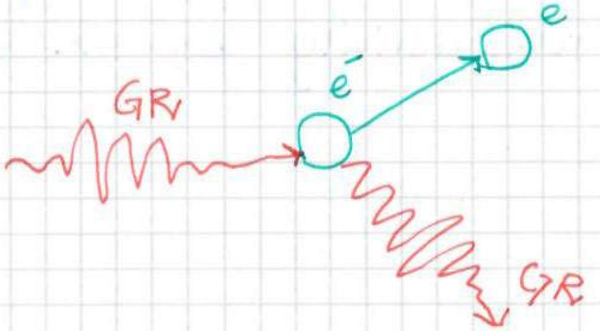
GR = highly energetic formation of electromagnetic radiation

Me V, KeV (mega, kilo)



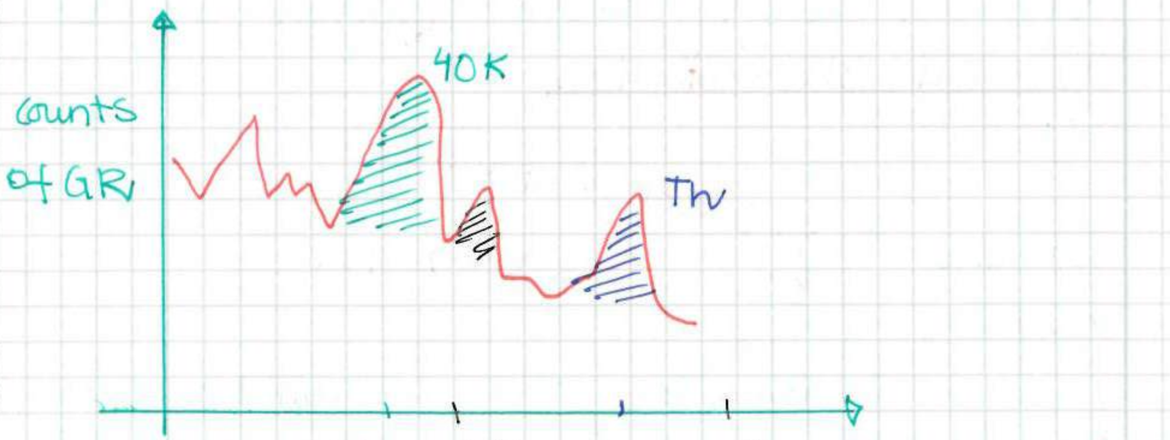
Compton Scattering

GR looses its energy when passing through any formation



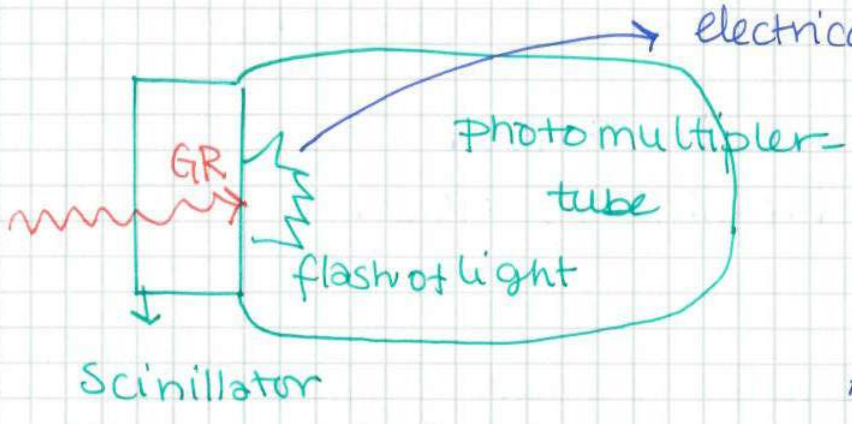
dens formation	less dense
a lot of e⁻	few e⁻
high energy loss	low energ loss

Reciever = contineous spectrum of values



Tool WL

- Simple GR tool



count crystal 2cm x 5cm

Units

APi = american Petroleum Institute

$1 APi = \frac{1}{200}$ [highest value count - lowest]

400 APi ⇔ shale ✓

- Spectral GR tool

- crystal 4,5 cm x 30,5 cm
- flash of light propotional to GR energy ⇒ K, U, Th

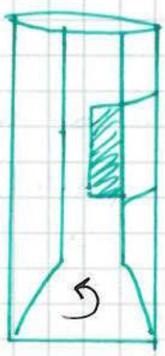
Relative count of K, V, Th, aaccording to their abundance in the earth

K	Th	U
2,59%	12ppm	3ppm

- WL tool 30 cm / min

- LWD tool

Reading 30 cm / min.
16/8 of the borehole



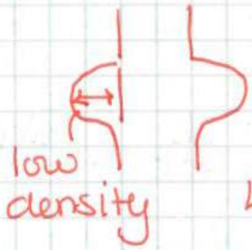
crystal behind 5cm of steel
⇒ decrease GR detection

Image logs

high API (shale) = light colour
low API (Reservoirs) = dark colour

- vertical resolution : 40cm
  depth of investigation : 10cm

- connections
  WL Radioactive element in the mud
  large caving.



Radioactivity of shale & Clay

LWD absorbtion by steel tool of GR

clay = mineral (aluminium, silicate)
(V clay)

shale - sedimentary rock imposed by compaction of clay ang Quartz.

(Vshale)

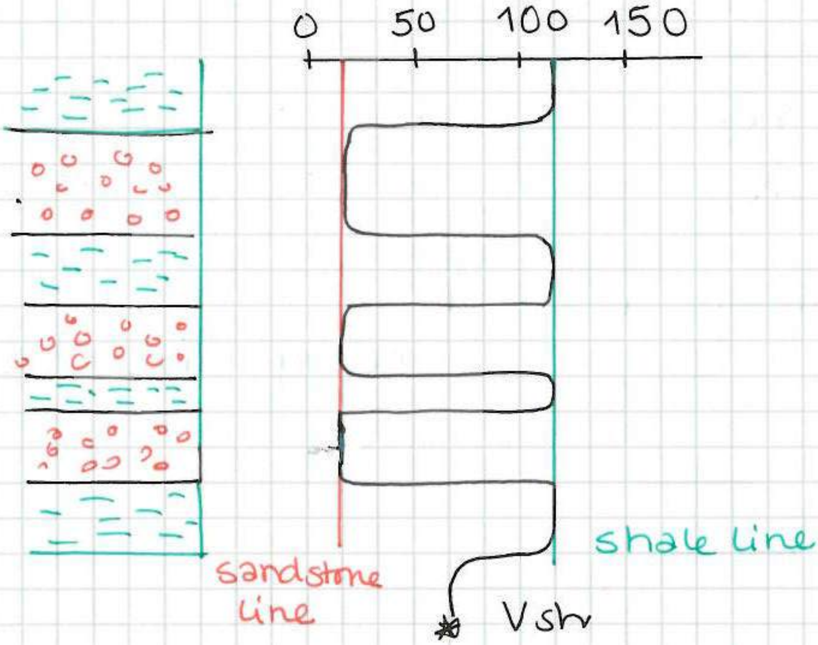
(K) chemically combined to clay
silicate/ Feldspar

shale = 2% of total K
good shale indication.

(U) contained in sea water
- small amount precipitate → sediments
- found with organic matter.
  ⇒ poor shale indicator

(Th) not soluable and part of Clay mineral
Shale = 40 - 50% of the total fraction of Th
very good shale indicator.

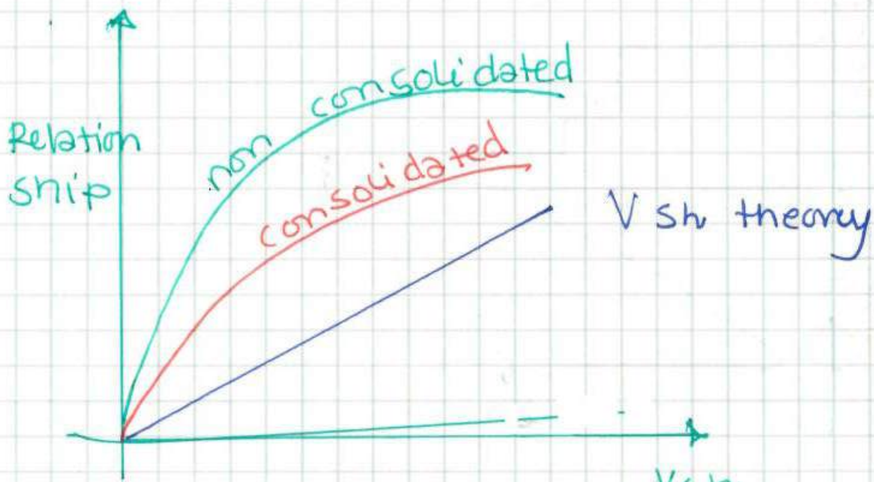
① Shale - sand line



② Volume of shale Vsh

$$V_{sh} = \frac{GR_{log} - GR_{sand}}{GR_{sh} - GR_{sand}}$$

surestimate Vshale



- non consolidated (Post tertiary)

$V_{sh} = 0{,}33 \left(2^{2V_{sh}} - 1\right)$

- consolidated (older rock)

  $V_{sh} = 0{,}083\ (2^{3{,}7V_{sh}} - 1)$

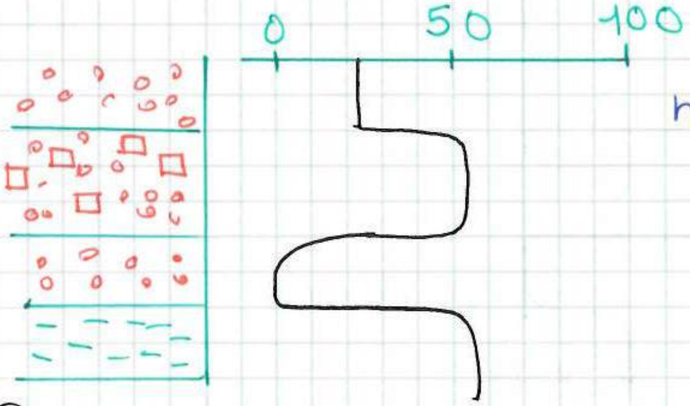
spectral GR

to compute V_{sh}, use of Th log.

③ Radioactive minerals

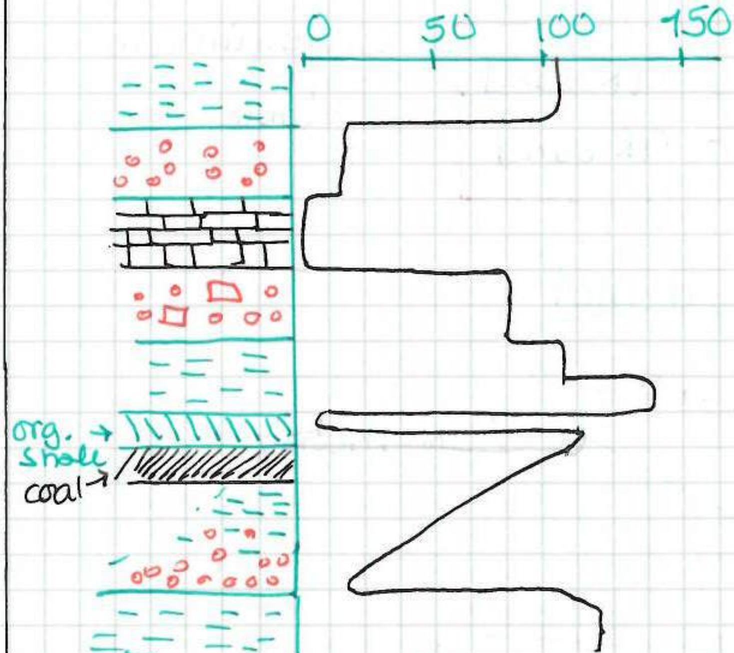
Feldsspar → K

micas → K



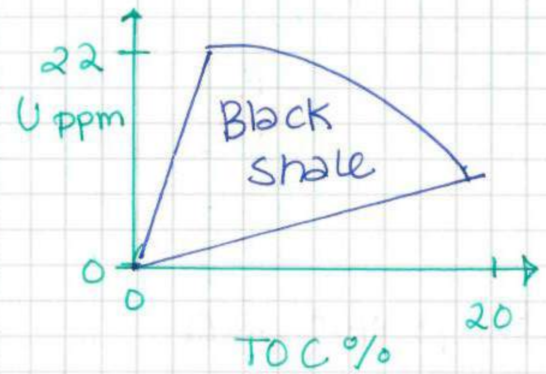
heavy mineral → Th

④ Lithology



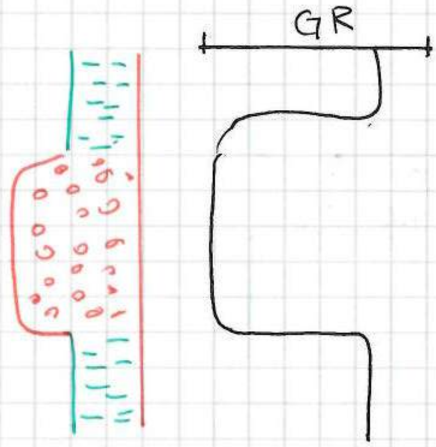
⑤ Source rocks

organic shale, black shale → (U)'



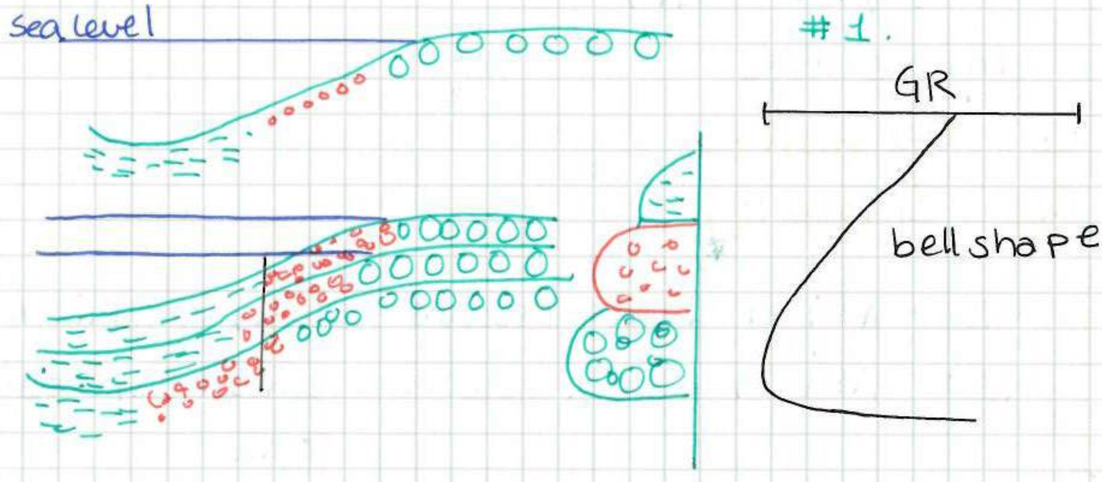
⑥ Sedimentology

① Uniform deposition



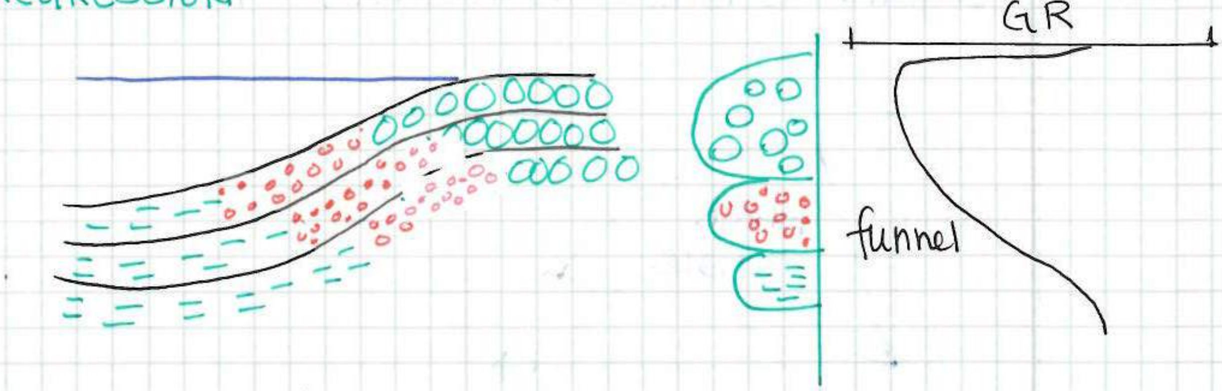
② fining upwards sequence

TRANSGRESSION ⇒ increase of sea level



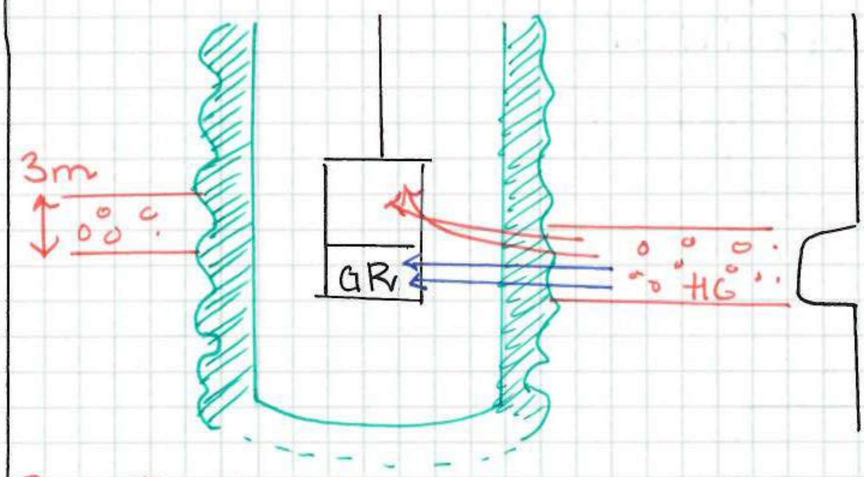
③ Coarsening up sequence

REGRESSION



⑦ depth adjustment perferation

→ good vertical resolution



⑧ Fractures

fracture full of formation water

U → water

→ picin GR

Image logs

⑨ Geo steering

⑩ Image log

high API → light colours, shale, organic matter

low API → dark colours, sandstone, carbonates coal.

Density log

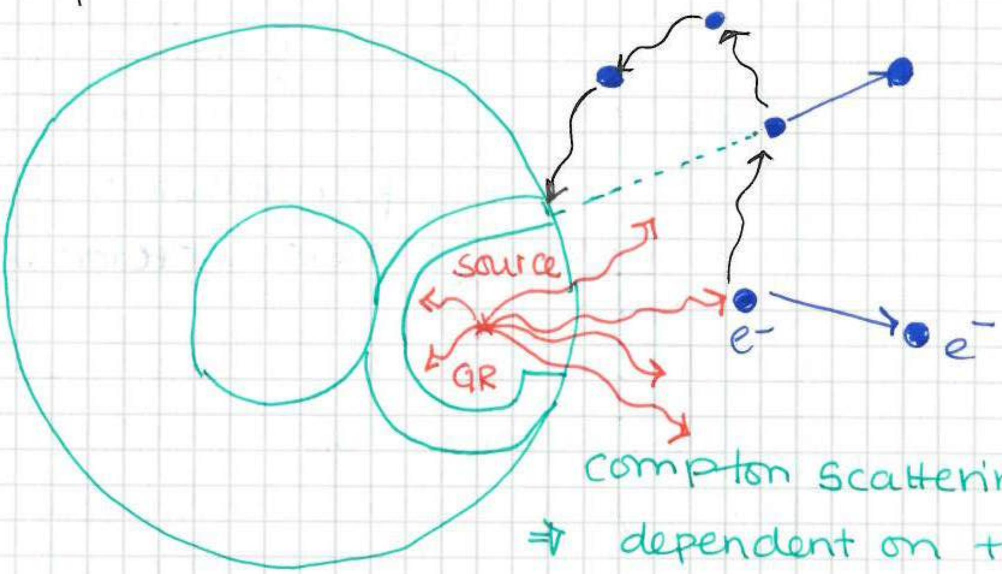
Gamma - Gamma

continous record formations

bulk density ρ_b

$$\rho_b = \rho_f \Phi + \rho_g (1 - \Phi)$$

Principles

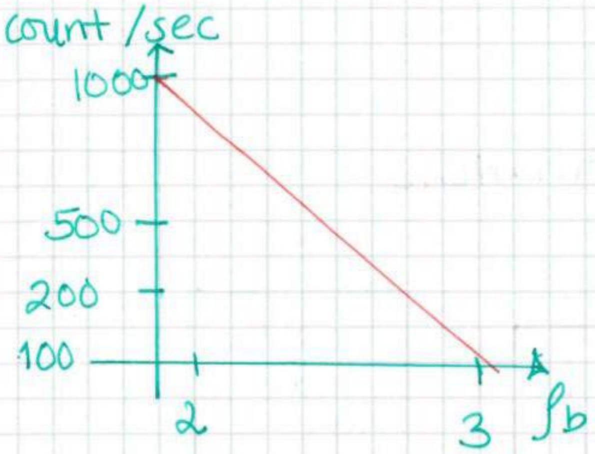


compton scattering

⇒ dependent on the density in e^- of the formation.

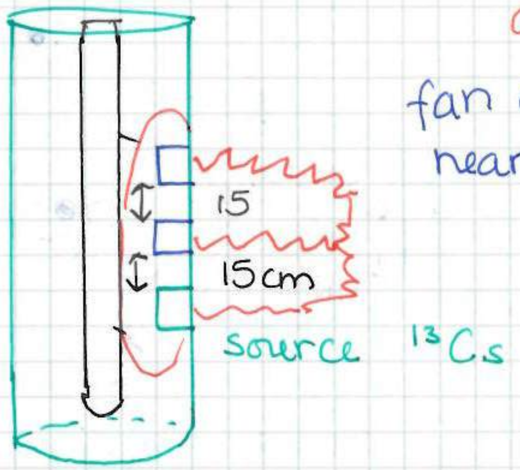
- The denser the formation, the more e^- there are less GR that come back to reciever at the tool.
- less dense, less e^- { - more GR at reciever - higher count of GR

detector = converts the GR count into ρ_b (g/cm^3)



TOOLS

WL

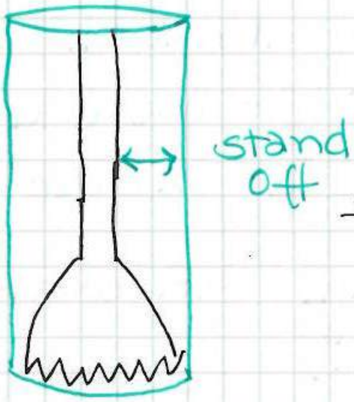


FDC = Density formation compensated tool

fan detector } correction
near detector } for mud cake

Depth of investigation
5 - 10 cm
vertical resolution
25 cm.

LWD source and detector seperated from wall



→ correction for stand off
(Caliper)

for near dectectors should have some measurement
4 not = corrected ρ = delta ρ_b DRHOB

Because - the tool not agianst borehole
- mudcake

units g/cm^3 1,95 ——— 2,95
cc
RHOB g/cm^3

image log

dark colour → light colours
low ρ high ρ

① Porosity

$\rho_b = \rho_f \Phi + \rho_g (1-\Phi)$

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

$Qz = \rho_{ma} = 2{,}65\ g/cm^3$

$\rho_f = 1 g/cm^3$

$\rho_{f\ correct} = \rho_{mf} S_{xo} + \rho_{hR}(1 - S_{xo})$

S_{xo} ↓ flushed zone

- gas effect ⇒ low ρ
⇒ overestimation of Φ_D

② Seismic - acoustic impedance.

sonic log, $R_i = \dfrac{\rho_{formation} \cdot V_{formation} - \rho_m V_{mud}}{\rho_f V_f + \rho_m V_m}$

③ formation strength

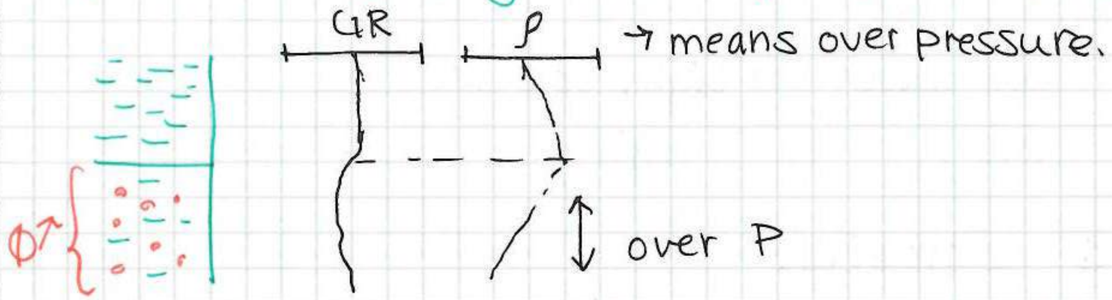
Bcp, chart ⑥ with Δt.

④ High pressure zone

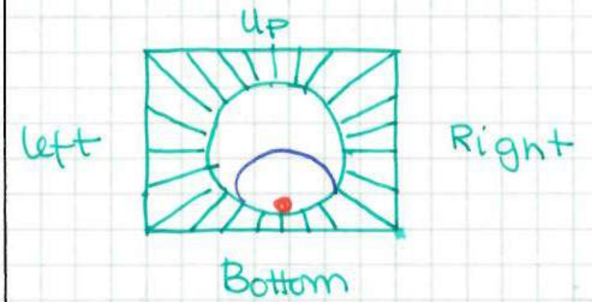
ϕ ↘ (decreasing) with depth

ρ ↗ (increasing) with depth

if ϕ↗ suddenly with depth ⇒ overpressure.

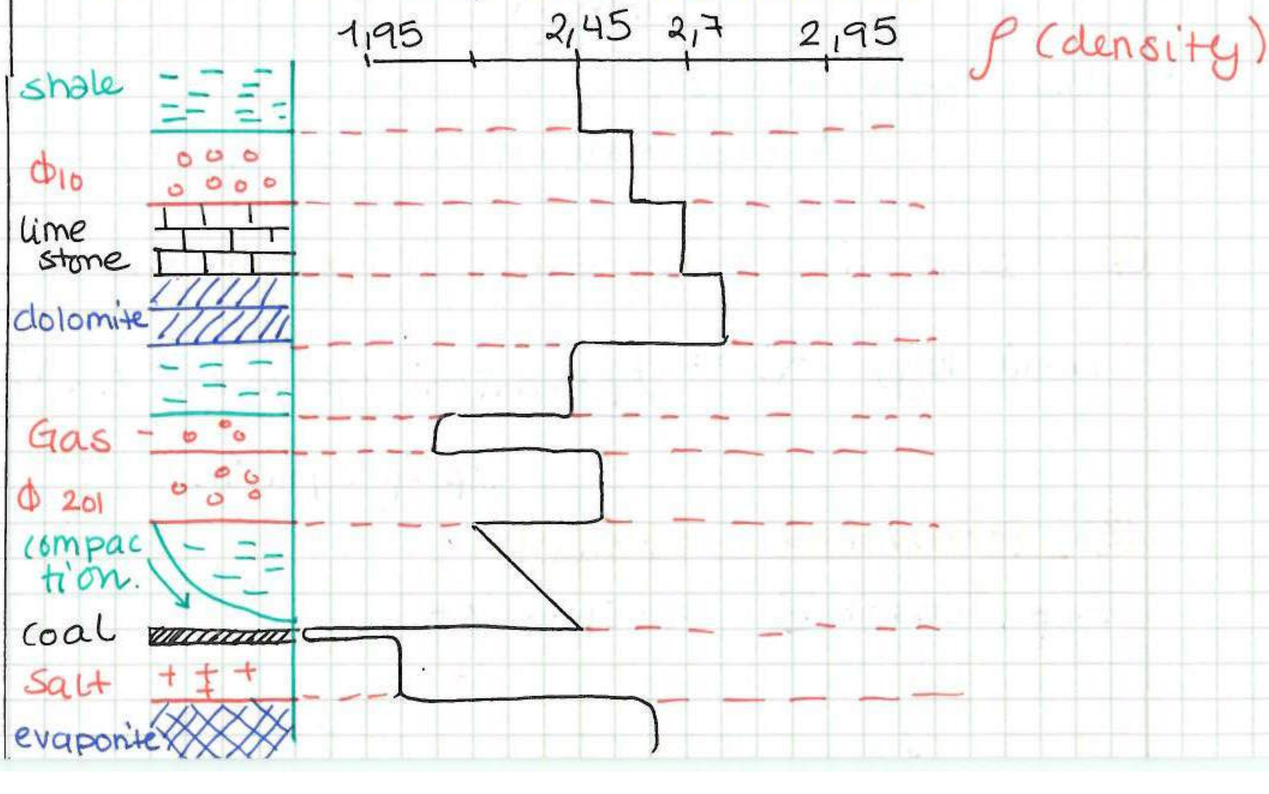


⑤ Geosteering LWD



↓ dark low ρ
light high ρ

16 sectors, keep best measurement.



Neutron Log

continoues record of formation. Reaction to neutron bombarment.

Hydrogen index.

Principles

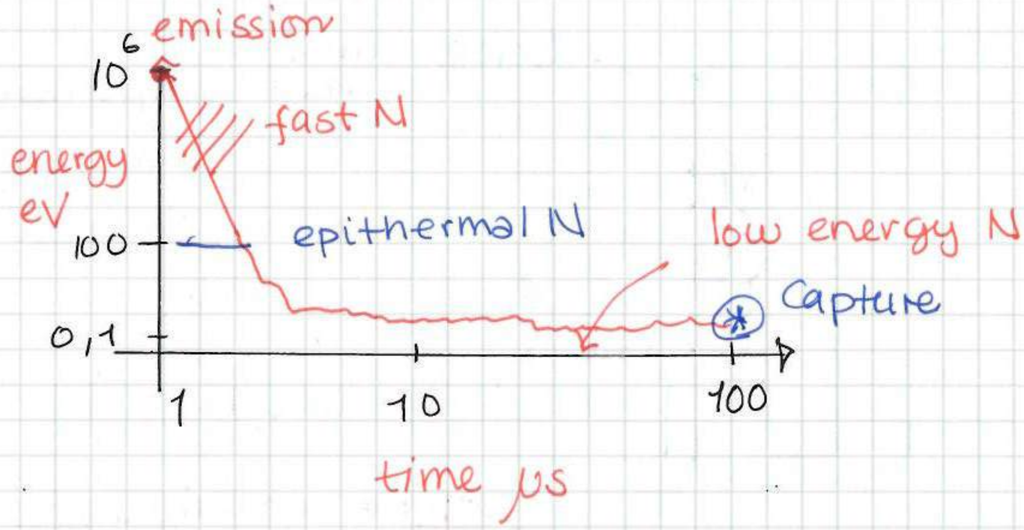
① Neutron emission from source :

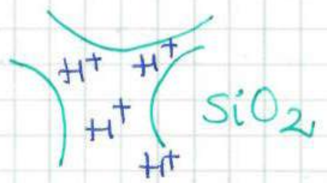
- high energy N
- fast N

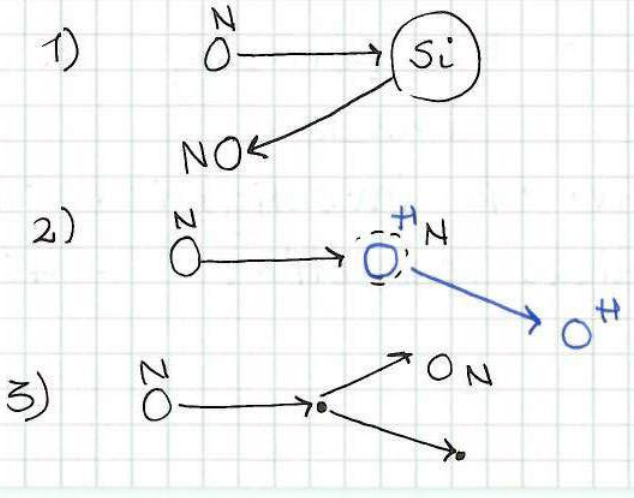
{ chemical, pulse N generator.

② Neutron scattering :

interaction with other atoms in formation.







The smaller the mass difference the greater is energy loss.

⇒ the more H in formation, the neutron slow fast and are captured.

③ Capture of low energy N Diffusing N

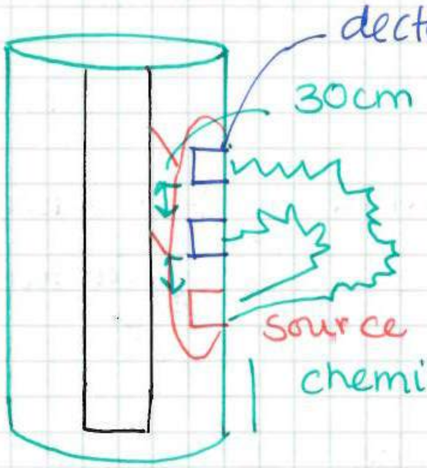
ex. number of collision to slowdown N

N − H = 16

N − C = 110

N − O = 137

WL



CNL = compensated neutron log

SNP = sidewall neutron log

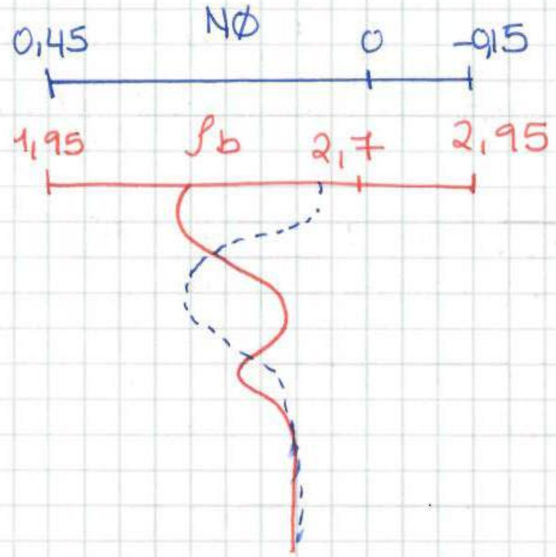
LWD := chemical soure correction for mud.

units Neutron porosity NΦ

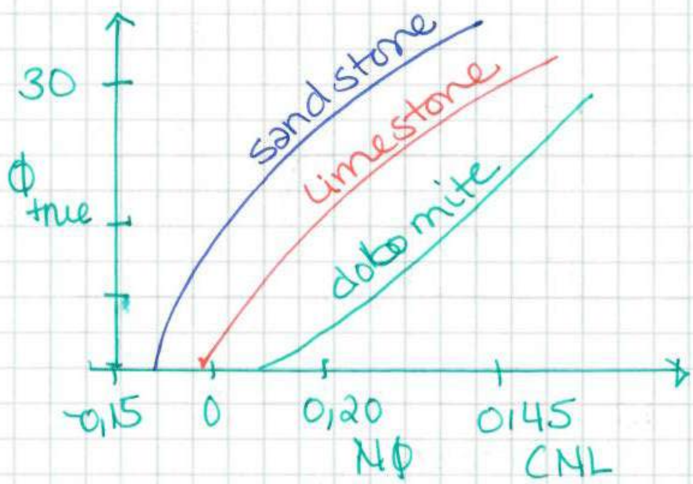
NΦ = true porosity in clean water filled Limestone.

depth of investigation = 15 − 25cm

vertical resolution = 40 − 60cm



① Porosity



corrected for Φ_N for CNL :

$\Phi_{N\,ss} = \Phi_N + 0{,}04$

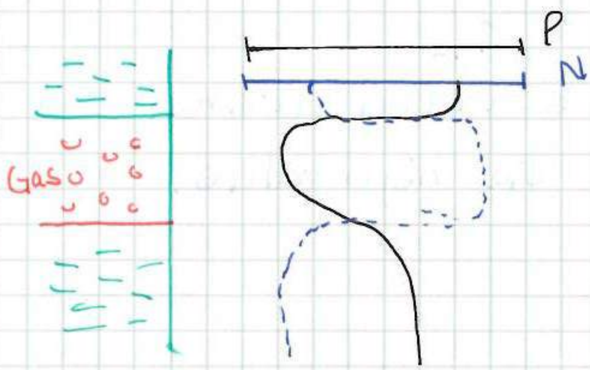
Φ_N limestone $= \Phi_N$

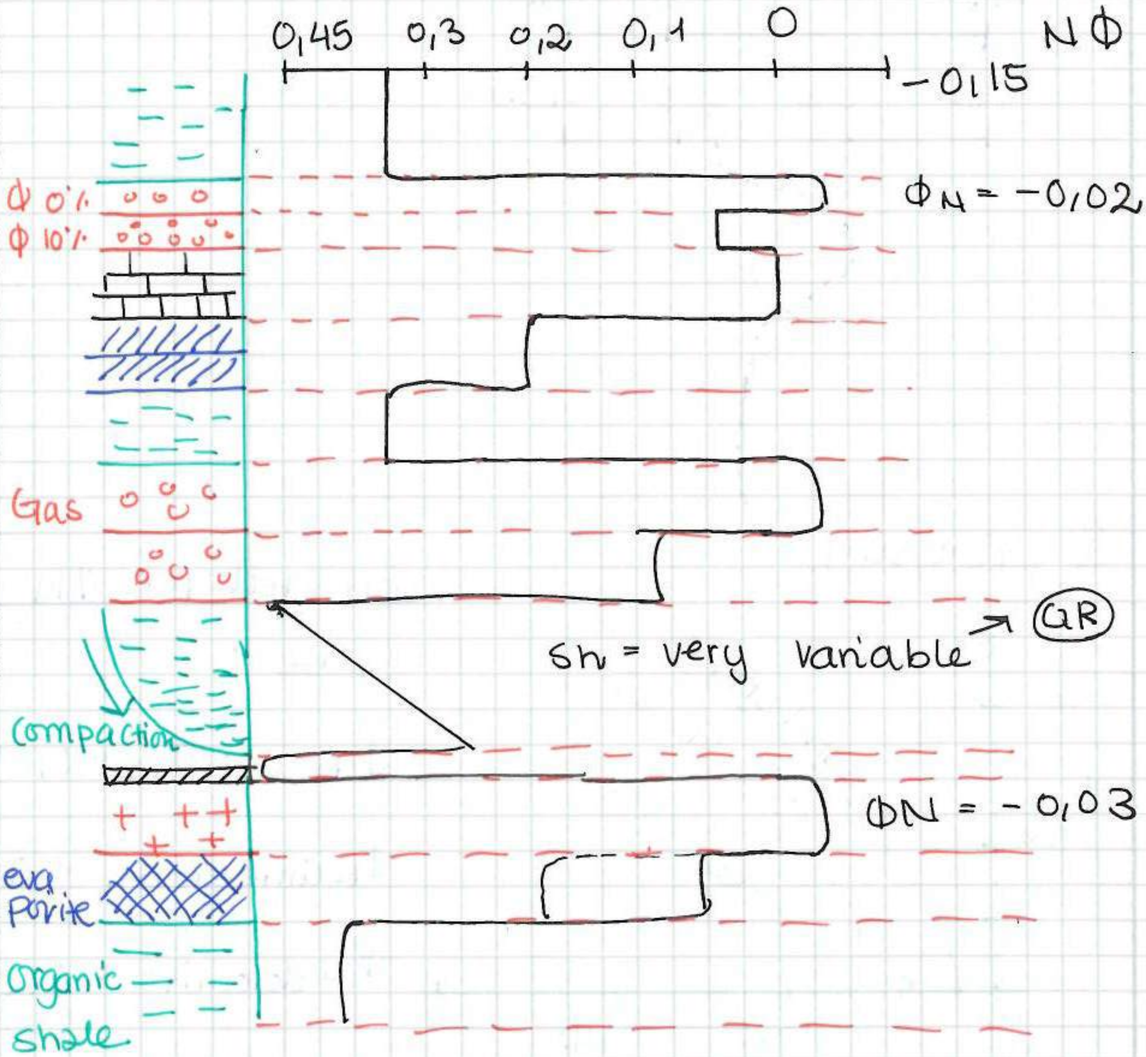
Φ_N dolomite $= \Phi_N - 0{,}07$

② true porosity Φ_D, Φ_D

Charts 8-14

gass effect => underestimation of Φ_N





③ Minerals

evaporite — salt water crystallization

salt NaCl high ΦN $\Phi_N = 0$

hydrated ions ↑ Φ_N

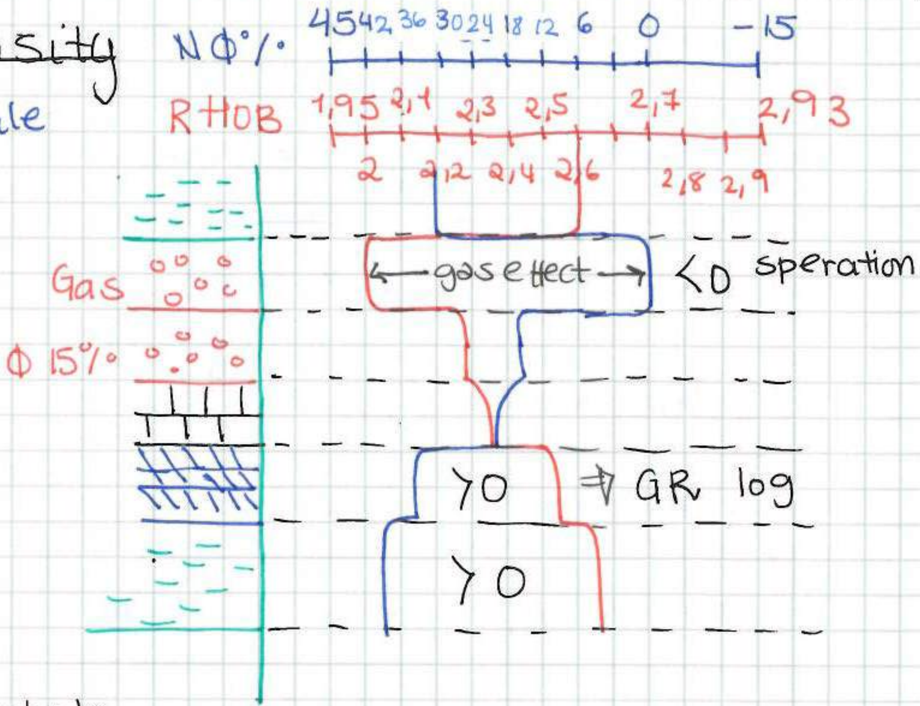
igneous rock = bounded water

Φ_N high value.

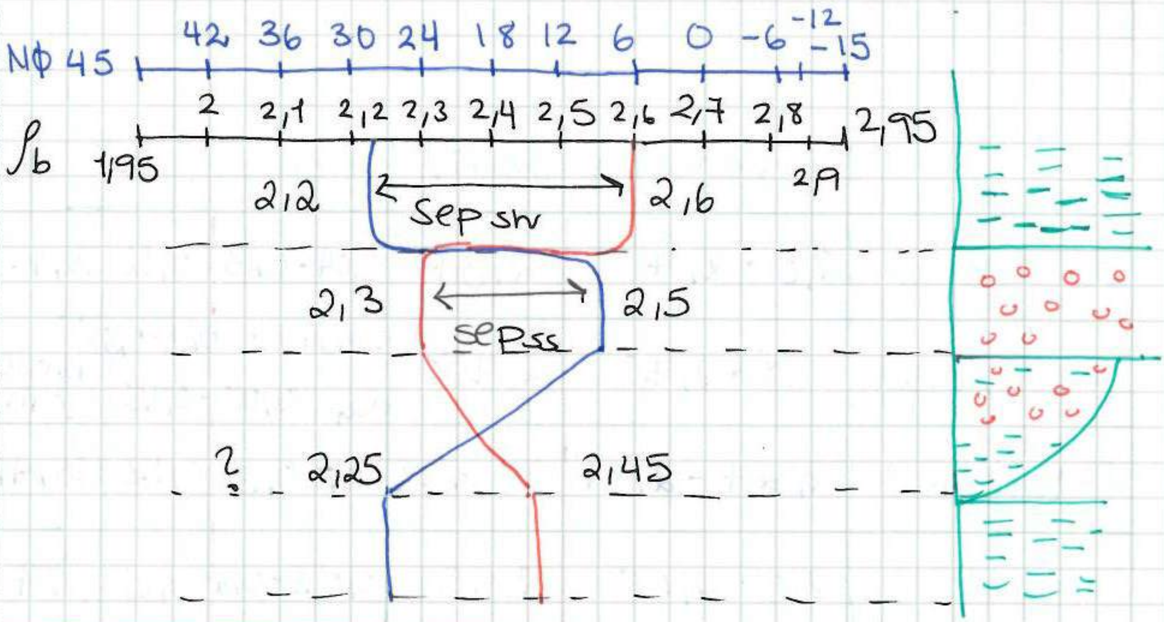
09/04

Neutron-density

limestone scale



Volume of shale



$$V_{sh} = \frac{Sep_{log} - sep_{ss}}{Sep_{sh} - Sep_{ss}}$$

Porosity

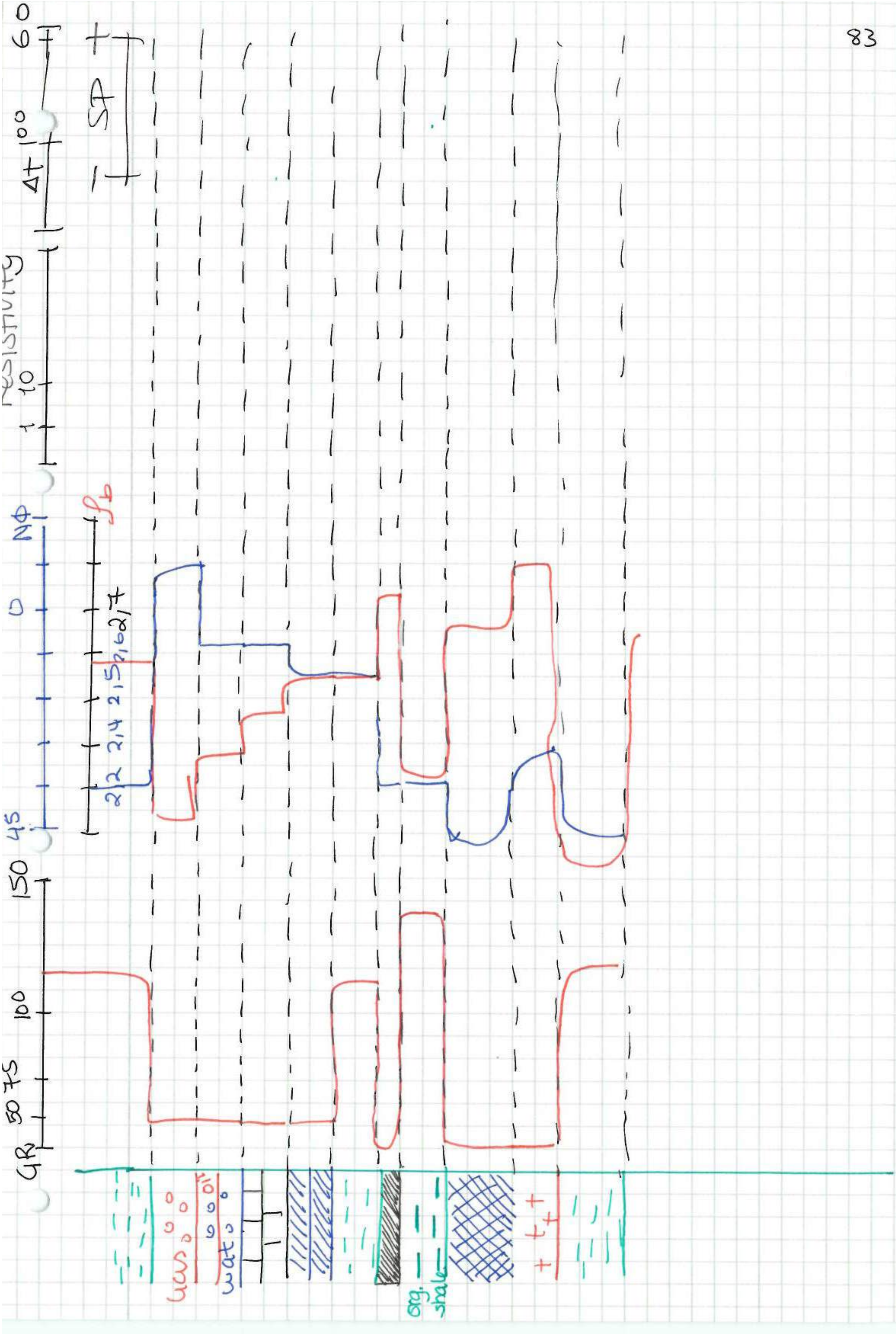
true porosity from { RHOB, NØ

charts 8 → fresh water } SNP tool
9 → salt water } SNP tool
11 → fresh, 12 → salt } CNL tool

Grains density g/cm^3

Quartz	$\rho_{Qz} = 2,65$
Calcite	$\rho_{ca} = 2,71$
Dolomite	$\rho_{Do} = 2,85$
Anhydrite	$\rho_{an} = 2,96$
salt (halite)	$\rho_{salt} = 2,165$
clay	2,65 - 2,7

	Density (g/cm^3)		Porosity		Vp km/s	
sandstone	2,0 - 2,7	2,37	0,04 - 0,3	0,16	3,1 - 5,5	4
Shale/clay	1,8 - 2,75	2,45	shallow 0,3-0,5 deep 0,05 - 0,15		large range	2
Dolomite	2,27 - 2,84	2,7/2,8	0 - 0,3	0,13	3,41 - 7	5,39
Limestone	2,0 - 2,65	2,45	0,03 - 0,4	0,15	?4	


GR
50
75
100
150
45
0
NΦ
ρ_b
2,2
2,4
2,5
2,62
2,7
Resistivity
1
10
100
Δt
60
SP
gas
oil
wat
org. shale

Porosity logs

Density log ⇒ $\phi_D = \dfrac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$

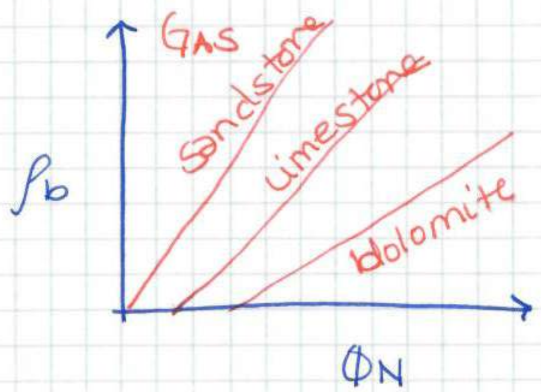
Neutron porosity ⇒ ϕ_N + correction

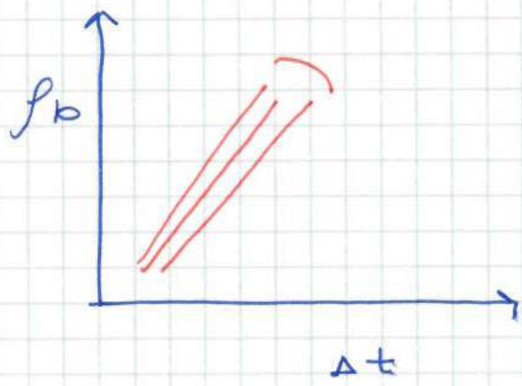
Sonic Δt ⇒ $\phi_s = \dfrac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$

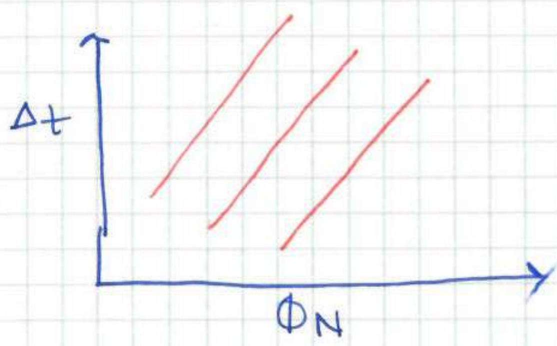
From the R_t

$$F = \frac{0{,}62}{\phi^{2{,}15}} \Rightarrow \phi = \left(\frac{0{,}62}{F}\right)^{1/2{,}15}$$

Cross plots :







10/04/14

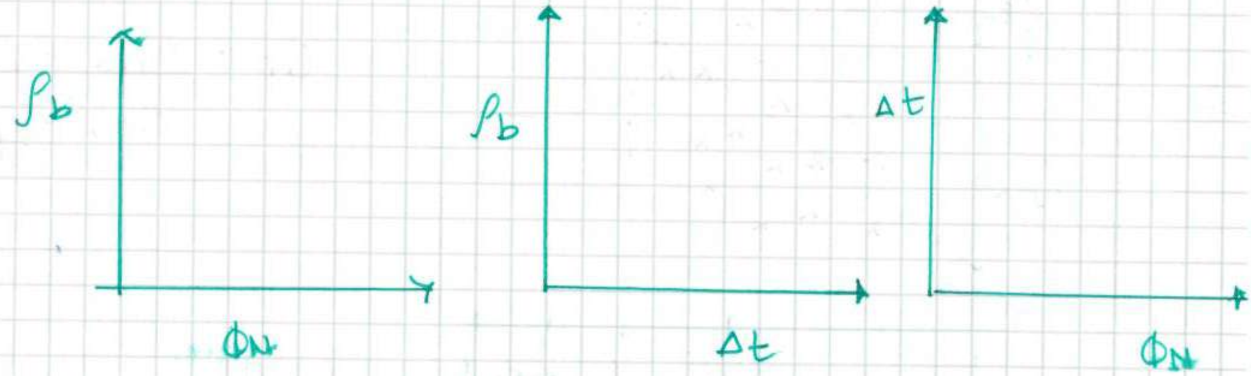
Porosity logs

- Density ⇒ $\Phi_D = \dfrac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$, $\rho_f = 1 g/cm^3$

- Neutron ⇒ $\Phi_N =$ $\Phi_{N\,ss} = \Phi_N + 0{,}04$
  $\Phi_{N\,lim} = \Phi_N$
  $\Phi_{N\,Dolo} = \Phi_N - 0{,}07$

- Sonic $\Phi_S = \dfrac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$, $\Delta t_f = 189\,\mu s/ft$

Φ → crossplots



water saturation Sw

Resistivity log Rt (oil zone) Rt

$$S_w = \sqrt{\frac{F \times R_w}{R_t}}$$

$$F = \frac{R_0}{R_w}$$ → water zone

$$F_{ss} = \frac{0{,}62}{\Phi^{2{,}15}}$$

$$F_{lim} = \frac{1}{\Phi^2}$$

Residual S_{xo} Flushed zone
(in oil zone)

$S_{HR} = 1 - S_{xo}$

$$S_{xo} = \sqrt{\frac{F \times R_{mf}}{R_{xo\,(oil)}}} \quad F = \frac{R_{xo\,wat}}{R_{mf}}$$

Gas correction

$\rho_{HC} < 0,7\ g/cm^3$

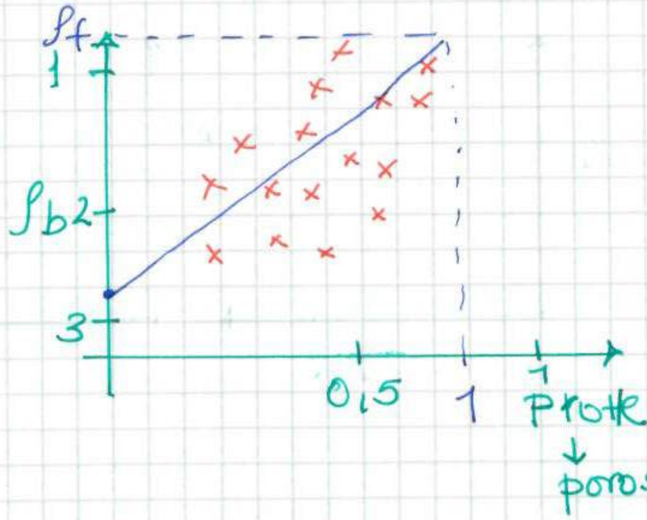
① only from logs

(a) $\Phi = \sqrt{\frac{\Phi_D^2 + \Phi_N^2}{2}}$ — Φ_N corrected, Φ_D with $\rho_f = 1 g/cm^3$

(b) chart ⑰

$\Phi = \Phi_1 + \Delta\Phi$ — we need S_{HR} for this

② log + cores - TROLL method



$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$ (ρ_b → log)

excercise 2 :

Porosity at 900m

Ss : $\rho_{ma} = 2,65\ g/cm^3$ — GAS → correction

$\rho_b = 2,22\ g/cm^3$

$\Phi_N = 0,06$

$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} = \frac{2,65 - 2,22}{2,65 - 1} = 0,26$

correction gas effet

$$\phi = \sqrt{\frac{\phi_D^2 + \phi_N^2}{2}} = \sqrt{\frac{0{,}26^2 + 0{,}06^2}{2}} = 0{,}19$$

always prefer this calculation, instead of the graf (chart 11)

Porosity at 930 m

only chart 11

$\phi_N = 0{,}19$
$\rho_b = 2{,}28\ g/cm^3$ } $\phi = 23{,}5\%$.

Porosity at 950 m :

Chart 11

$\phi_N = 0{,}24$
$\rho_b = 2{,}3$ } $\phi = 0{,}245 = 24{,}5\%$

$F = \frac{R_o}{R_w}$ R_o only avialable in limestone

1) R_w is considered as constant in the entire section.

We can compute F in limestone.

$$F = \frac{1}{\phi^2} \quad \frac{1}{0{,}245^2} = 16{,}6 = F$$

$$R_w = \frac{R_o}{F} = \frac{2}{16{,}6} = 0{,}12 = R_w\ \Omega m$$

we can use for all calculation.

- S_w in Ss at 900 m

Archie $F = \frac{0{,}62}{\phi^{2{,}15}} = \frac{0{,}62}{0{,}19^{2{,}15}} = 22 = F$

$$S_w = \sqrt{\frac{F \times R_w}{R_t}} = \sqrt{\frac{22 \times 0{,}12}{85}} = 0{,}18 = S_w$$

means 82 % gas in reservoar.

- S_w in Ss at 930 m

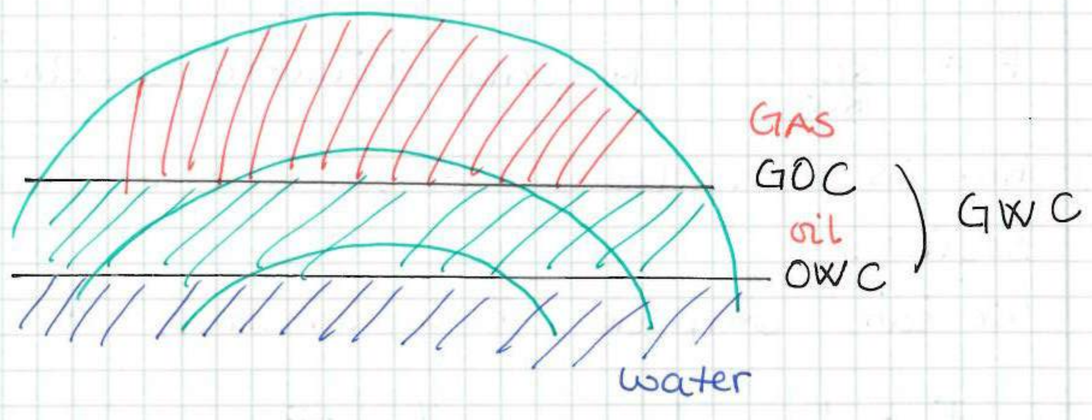
$$F = \frac{0{,}62}{0{,}235^{2{,}15}} = 14$$

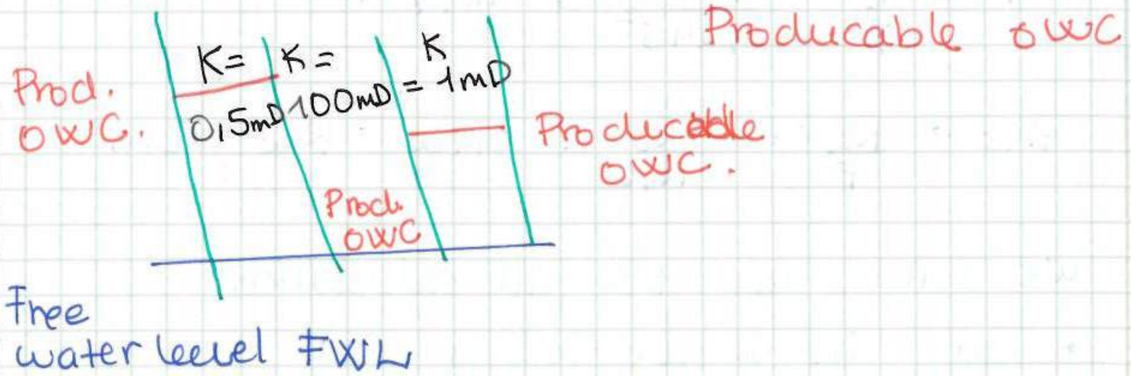
$$S_w = \sqrt{\frac{14 \times 0{,}12}{70}} = 15{,}55$$

- S_w at 950

$$S_w = \sqrt{\frac{R_o}{R_o}} = \underline{1}$$

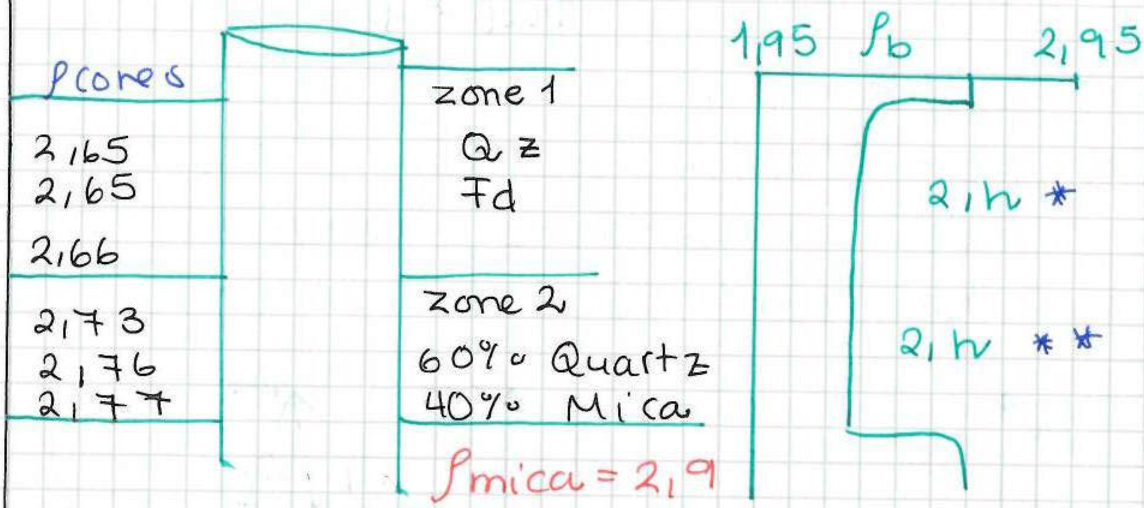
Fluid contacts





models of computation

minerology from logs



$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} = \frac{2{,}65 - 2{,}}{2{,}65 - 1}$$

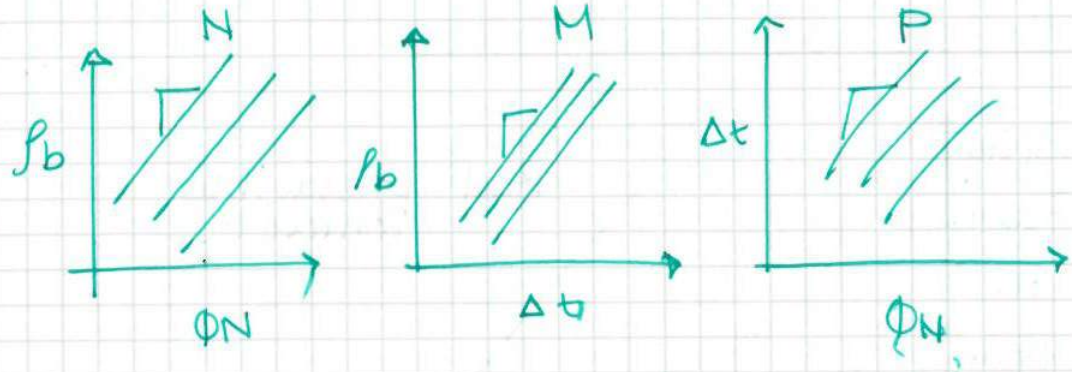
$\rho_{Qz} = 2{,}65$

$\rho_{Fd} = 2{,}65$

* $\Phi_D = 0{,}15$

$$\Phi_D = \frac{(\rho_{Qz} \times 0{,}6 + \rho_{mica} \times 0{,}4) - \rho_b}{\text{———— '' ————} - \rho_f}$$

** $\Phi_D = 0{,}2$



$$M = \frac{\Delta t_f - \Delta t}{\rho_b - \rho_f} \qquad P = \frac{N}{M} = \frac{\phi_{Nf} - \phi_N}{\Delta t_f - \Delta t}$$

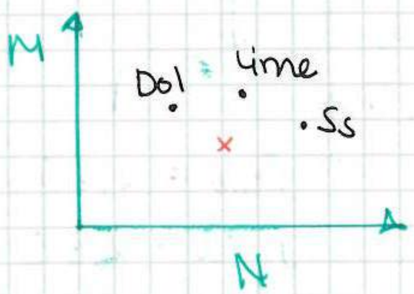
$$N = \frac{\phi_{Nf} - \phi_N}{\rho_b - \rho_f}$$

$\rho_f = 1.0 g/cm^3$ $\Delta t_f = 189 \mu s/ft$

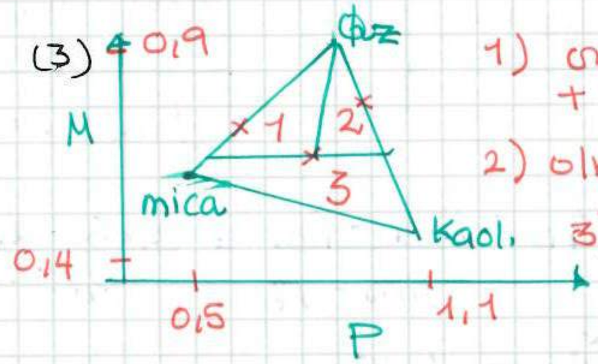
$\phi_{Nf} = 1$

1) compute M, N, P
2) plot M and N on chart 14 → if the points don't correspond to minerals
3) chart from ex. 6.

(2)



(3)



1) only mica + Qz
2) olny Qz Kao
3) Qz + Kao + Mica

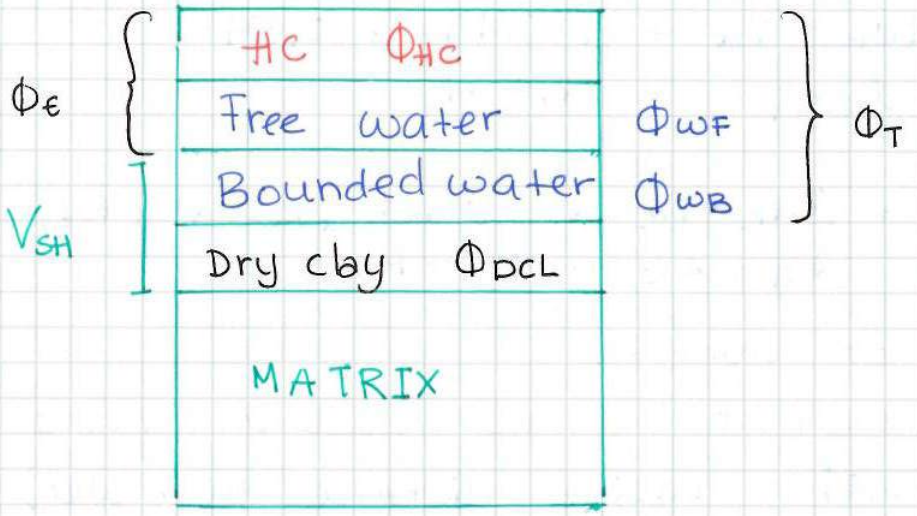
4) to plot ρ_{mal} / ϕ_{min} on Chart 11

Mica

Quartz

Kao

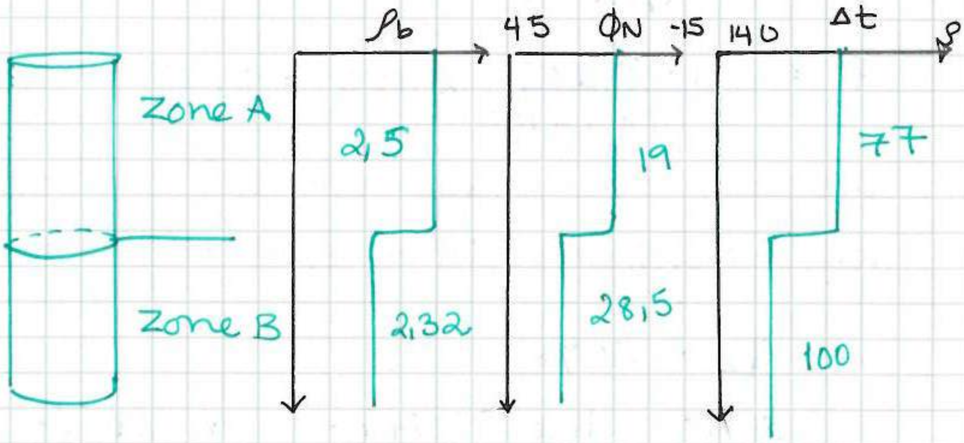
23/04 **Total and effective porosity and saturation**



$$S_{wT} = \frac{\Phi_{wB} + \Phi_{wF}}{\Phi_T}$$ ← Total Φ

$$S_{wE} = \frac{\Phi_{wF}}{\Phi_E}$$ ← effective

Question 6



$\rho_f = 1,0\ g/cm^3$ Not given, but known.
$\Delta t_f = 189\ \mu s/ft$
$\Phi_{Nf} = 1$

Zone A : determination of M, N and P

$$M = \frac{\Delta t_f - \Delta t}{\rho_b - \rho_f} \times 0,01$$

$$M = \frac{189-77}{2{,}5-1} = 0{,}75$$

$$N = \frac{\Phi_{Nf} - \Phi_N}{\rho_b - \rho_f} = \frac{1-0{,}19}{2{,}5-1} = 0{,}54$$

$$P = \frac{N}{M} = \frac{\Phi_{Nf} - \Phi_N}{\Delta t_f - \Delta t} = \frac{1-0{,}19}{189-77} \times 100 = 0{,}72$$

if not chart 14,

MP - crossplot A is close to Quartz - Mica line.

Qz = 65% (using distance from ruler)

Mica = 35%

zone B

$$M = \frac{189-100}{2{,}32-1} * 0{,}01 = 0{,}67$$

$$N = \frac{1-0{,}285}{2{,}32-1} = 0{,}541$$

$$P = \frac{1-0{,}285}{189-100} \times 100 = 0{,}80$$

sandstone of Breut formation ⇒ main mineral quarts

long redline/ position of B ×100% = 0,50

Qz = 50%

50%	Kao	54%	→ 27%
	Mica	46%	→ 23%

From cross plot $\rho_b / N\Phi$ (chart 11)

Φ_A = 14%

From ρ_b, Φ_N, (chart 11), we found

Φ_B = 19%

crossplot ρ_b, Δt = Φ_A = 14%

Crossplot ρ_b, Δt = Φ_B = 18,5 %

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} = \frac{(2{,}65 \times 0{,}65 + 2{,}9 \times 0{,}35) - 2{,}5}{(2{,}65 \times 0{,}65 + 2{,}9 \times 0{,}35) - 1}$$

$\underline{\underline{\Phi_{DA} = 0{,}135}}$

$$\Phi_{DB} = \frac{(2{,}65 \times 0{,}50 + 2{,}32 \times 0{,}27 + 2{,}9 \times 0{,}23) - 2{,}32}{(\text{———— '' ————}) - 1}$$

$\underline{\underline{\Phi_{DB} = 0{,}184}}$

Brønn 7122/7-3

RFT/TVDMSL (MDT Pressure) table.

1. GOC, OWC ?

large seperation between neutron and density
→ gas
small seperation
→ oil
GOC can be drawn by looking at density, neutron
seperation log.

lot of gas → overpressure
when density, neutron graf is together,
peak in sonic, Resistivity, may be
Limestone. (or sandstone)
neutron log - dashed line
density log - solid line

4 pics → really high density 2,9 and more
chart ⑪ → anhydrite
but maybe dolomite
with low porosity

other data to determine core
data or out drilling data.

(3)

	GR	ρ_b	Φ_N	Δt	R_t
1090 m gas	65	1,98	0,02	118	700
1147 m oil	70	2,17	0,27	108	500

• 1090 m : → Gas correction

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} = \frac{2,65 - 1,98}{2,65 - \underbrace{1}_{\text{wrong for gas}}} = 0,41$$

$\Phi_N = 0,02 + S_s$ correcte ction $= 0,02 + 0,04 = 0,06$

gas correction :

$$\Phi = \sqrt{\frac{\Phi_D^2 + \Phi_N^2}{2}} = \Phi = 0,29$$

$$S_w = \sqrt{\frac{F \times R_w}{R_t}} =$$

$$F = \frac{0,62}{\Phi^{2,15}} = \frac{0,62}{0,29^{2,15}} = 8,87$$ in HC zone

R_w in water zone : , depth 1200m

$$R_w = \frac{R_o}{F} = \frac{1}{F} = 0,12$$ $\boxed{R_w = 0,12}$

$$F = \frac{0,62}{\Phi^{2,15}}$$ in water zone

$\rho_b = 2,13\ g/cm^3$, $\Phi_N = 0,25$) chart 11 ⇒ $\Phi = 0,30$

$$S_w = \sqrt{\frac{8,87 \times 0,12}{700}} = 0,04$$

very high S_{HC} → coarse grains in Ss.

- **at 1147 m**

$\Phi_D = \frac{2,65 - 2,17}{2,65 - 1} = 0,29$

$\Phi_S = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} = \frac{108 - 55}{189 - 55} = 0,40$ check the consolidation factor chart ⑥.

chart ⑪ corrected Φ . $\Phi = 30,5$

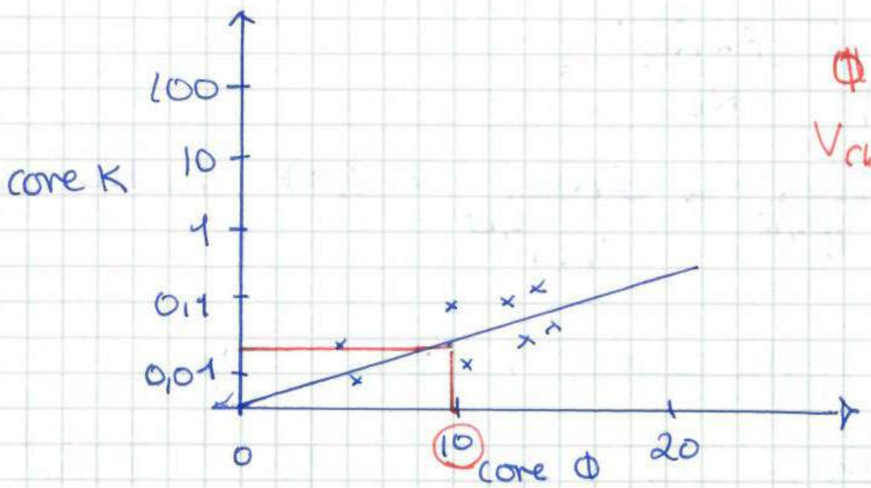
$B_{cp} = 1,35$

$\Phi s = \frac{\Phi s}{B_{cp}} = \frac{0,40}{1,35} = 0,296 = \Phi s.$

$S_w = \sqrt{\frac{\frac{0,62}{0,305^{2,15}} \times 0,12}{500}} = 0,04 \; S_w$

- Net sand (producable sand, clean sand)

K dependent $K > 0,05$ mDa



$\Phi > 0,10$

$V_{clay} < 0,40$

- Pressure

10m ⌋ } ↑ 1 bar

at 1100 we expect 110 bar (normal pressure)

- T° in borehole

sea bottom T = 5°C

2,8°C / 100m

$T = (1100 - 150) \cdot 0,028 + 5$

$= 31,6$ °C

solinity of sea water :
[30 000 - 40 000] ppm of salt in sea water.
determined by chart nr. 2.

- sand production problem
  Bcp : consolidation factor

  Bcp = 1,35 : not consolidated
  ⇒ sand production problem

Δt > 100 µs/ft ⇒ problem

Bcp > 1,2

exam

tool, effective porosity, total porosity
all theorectical questions will include sketches.
logs with good scale, ⇒ interpretations of logs
using 2 colours, Interpretation exercise.